File

FPL 659

WOOD AND FIRE

by

Association for the Development

of Wood Use--Paris, 1963

Translated from French
by
U.S. Department of Agriculture
Washington, D.C.
February 1966

FPL 659

WOOD AND FIRE[1]

Studies and documents assembled under the direction of the Association for the Development of Wood Use--Paris, 1963

PREFACE

Primitive peoples obtained fire by rubbing two pieces of wood together.

This archaic image remains alive in the unconscious mind and obliges us to see wood burning when we think of fire.

Certainly we cannot deny that there is a strong relation, conscious or more obscure, between wood and fire and that such relations do not exist with other materials, metal for example, as usually thought of.

No one pretends to contest the fact that wood has to be transformed into flames, heat, and ash, for our joy, our comfort, and alas, our pain.

From the point of view of safety against fire, this can result in a categorical attitude against wood, which should, we believe, be modified, because this last statement has to assume failure of the long-established commerce, since their origins, between man and wood. As far as we are concerned, we have no difficulty in wishing for the opposite.

Setting aside voluntarily all the subjective, esthetic, or functional reasons which can be pleaded in its favor, and considering only its general behavior when subjected to fire, we are able, without fear of contradiction, to speak of the "great loyalty" of wood.

It has in its combustion a notable freedom, a progressiveness of simple direct and indirect effects which make it the envy of other materials.

---

[1] Translated by Alan D. Freas for the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture.

We will go even farther.

One who has not heard the groan of wood, struck to the heart by flame, near collapse, is not able, in our view, to speak of its behavior.

Those who have to fight fire are pleased to recognize that a wood fire shows, with regard to its extinction, a frequently remarkable docility, and there are few examples known which would illustrate its malignity, its treachery, or its perfidy.

Also, it behooves all those who will decide to have recourse to it to find exactly the conditions in which its combustibility can be allowed. Our technicians and our laboratories are well equipped to define such ideas.

From another point of view, it is now possible to fix in a more and more positive and rational way what we have a right to require with respect to its resistance and its behavior in fire. We are getting progressively farther from the empiricism which ruled for some decades past of which the sometimes far too categorical condemnations are henceforth and from all evidence doomed to disuse.

We will have available, from now on, a complete range of degrees, of special properties, in what we have a right to require from a material with respect to fire. This range can only enlarge and diversify.

Currently, in the multiple forms which industry offers us, and taking account of the qualities which new experimentation permits us to enhance, wood seems to us to be perfectly capable of sustaining comparison with other traditional or new materials.

It is sufficient if one will concede that the criterion of incombustibility pure and simple is assuredly a simplified absolute if not to say over-simplified.

Colonel Beltramelli,

Regiment of Paris Fire-Fighters

INTRODUCTION

When a fire has broken out, public opinion intends immediately to find the cause and is prompt in advancing a simple reason to explain the origin of the disaster, the rapidity of the spread of fire, or the magnitude of the damage. If wood has been used in some part of the construction, it is rare that it is not from the very first considered the cause, and it is evident that, in a fire, wood structures frequently burn, at least in part. But, for all that, is wood the real cause of the fire and does it bear the responsibility for the gravity of the disaster? It is this which those who have experience with fire will refrain from affirming without proof, because the risk of fire is present in completely incombustible constructions.

However, the restrictions imposed on the use of combustible materials in buildings generally leave the impression that wood is a dangerous element of construction, and suffice to ban it in order to practically assure against any risk of fire and that from this, any other precaution becomes secondary. Too frequently the establishment and the maintenance of means of evacuation or the inspection of electrical or heating installations are thus neglected. Users permit themselves serious imprudences, such as unconsidered storage of dangerous materials or a lack of discipline of acts or actions which can induce fires and from which they probably would abstain in a construction which they believe more vulnerable.

As a matter of fact, the role which materials of construction, especially wood, play in the origin and development of fires is poorly known. Most frequently (at least 80 percent of cases) it is the building contents which ignite first and transmit the fire to the constructions. It is useful, however, to state precisely the reaction of wood to fire in order to deduce from it the precautions necessary in the choice and application of woody materials. But it is equally and especially necessary to study the behavior of structures in fire and to pursue indispensable investigations in order to better inform the public and to improve the current regulations established earlier and frequently unnecessarily severe.

Investigations must be carried out under conditions as close as possible to reality. This is why the Centre Technique du Bois is participating in studies undertaken at the test station of the Centre Scientifique et Technique du Batiment at Champs-sur-Marne.

We hope, in explaining objectively the state of knowledge in this area, to respond usefully to the legitimate preoccupations of the public and the authorities, contributing in this way, in some measure, to make better known and observed the indispensable precautions and to remove the prejudices which in many cases are shown to be poorly based.

We have wanted also to collect the advice of persons from the Services of Security and Defense Against Fire. We think, in fact, that whatever the concern of the experiments, no conclusion should be advanced which would be in contradiction to observations made daily by those whose task is to prevent fires or to fight them.

CHAPTER I

REACTION TO FIRE

Nothing is more familiar to man than the combustion of wood, which has so greatly contributed to the development of civilization. It is, however, not easy to make it flame; and wood, although it continues to be well appreciated as a combustible, has fast been replaced in its role of igniter by substances much more easily flammable.

Besides, to construct an initial source and to maintain a wood fire requires some precautions. The size of the logs, their dryness, the density of the combustible and the access of air controls the ignition and the total combustion.

Science shows us today that combustion is one of the forms of a definite chemical reaction--oxidation--and that this obeys the general laws of chemical combination.

First of all, the state of division of the material is involved. In order for a reaction to be started, it is necessary that there be intimate contact between the reactors. This rule applies to combustion, which does not occur if the combustible does not expose a large surface to contact with the oxygen of the air. It is very difficult to make a large log blaze; to attain this it is necessary to light kindling. The more or less compact structure of the different species of wood (which can be translated by the differences in density) and their chemical composition determine their more or less great ease of ignition; certain species catch fire rapidly, while others are very difficult to ignite.

In the second place, a minimum temperature is needed for starting a reaction. As concerns wood, live combustion does not occur at ambient temperatures, and it is absolutely necessary that it be heated in order for it to burn.

Numerous and interesting studies have given the ignition temperature for various bodies. The lower it is, the more dangerous is the body from the

point of view of fire risk. It will be noted that the smaller the material is cut, the easier the ignition temperature is reached.

1. Combustion of Wood

By an elevation of temperature, wood first loses progressively the water which it holds tightly. Prolonged heating above 100° C. is necessary to dehydrate it completely.

For a temperature well above 200° C., there occur in its mass some exothermic reactions with emission of partially combustible gases (pyroligneous acids and alcohols, carbon dioxide, and carbon monoxide). Beginning at this point, the reaction can continue by itself and be transformed into live combustion by the spontaneous ignition of the gas or, at a lower temperature, on contact with a flame or an external incandescent body.

The temperature of spontaneous or induced ignition is very difficult to determine exactly because it depends a great deal on the rate of heating. If the temperature rise is rapid, ignition does not seem to occur spontaneously below 370° to 400° C., but the ignition of the combustible gases can be induced at much lower temperatures (250° to 270° C.).[1] The temperature continuing to rise in the whole mass of wood because of the exothermic reactions and the live combustion on the surface, the proportion of combustible gases, notably carbon monoxide, increases (350° C.). Then (fig. 1) tars and hydrocarbons resulting from the partial destruction of the tars appear. The residue of carbon, or charcoal, becomes incandescent and burns beginning at 350° C.

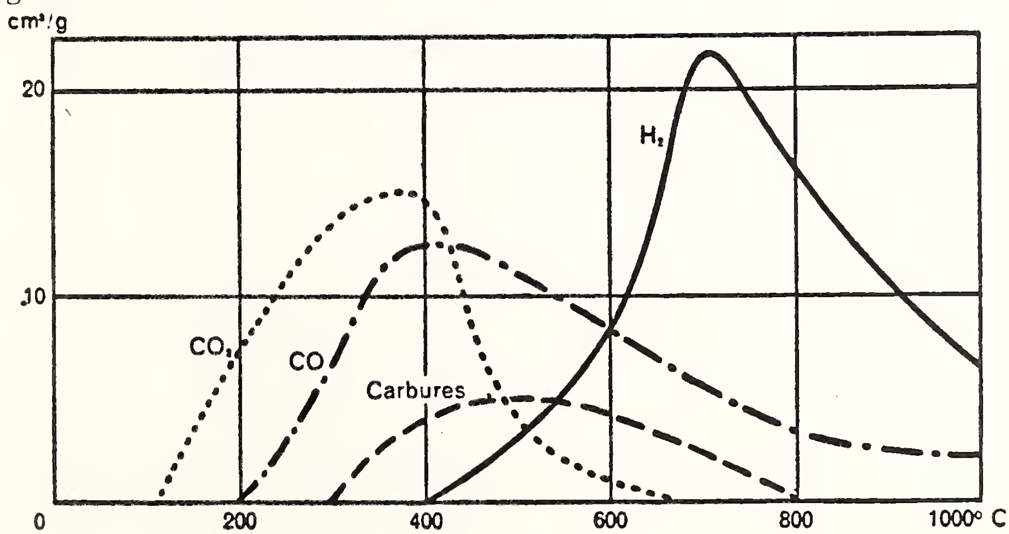


Figure 1.--Volatile products of the decomposition of wood by heat. (carbures are hydrocarbons)

---

[1] This temperature corresponds to the initiation of exothermic reactions. The heating of wood can thus be continued and its spontaneous ignition occur by prolonged heating at 270° or 280° C.

In order that the combustion of wood be complete, it is necessary that the temperature rise continually. The combustion at the initial ignition point and the internal exothermic reactions frequently furnish enough heat for the reaction to continue at this point. At the same time, radiation and thermal conduction in their turn heat the neighboring parts. Beginning at the center, where temperature increases more and more, the heat progressively reaches an increasing area where there are found successively all the phases of dehydration and of combustion.

The progression of the fire is much more rapid on the surface than in the interior because of radiation and of convection currents which spread the flame over the surface of the combustible and also because of free contact with the oxygen of the air. Inclination of the sample also strongly influences the speed of spread much more rapidly and essentially toward the top if it is vertical.

Toward the interior of the material, the heat of combustion is transmitted only slowly because wood is a poor conductor. As a result of lack of oxygen, the decomposition gases ignite only when they reach the surface.

It frequently happens that the heat given off by the initial ignition zone is dissipated without sufficiently heating the mass of wood. There is then auto-extinction if there is no supply of external heat to furnish the necessary energy, rapidly increasing, so that the combustion can continue.

Incandescence results from the combination of the oxygen of the air with the carbon formed by the destruction of the organic compounds of the wood (cellulose and lignin). This destruction begins toward 275° C. and the carbon burns in air toward 350° C., liberating a new quantity of heat which contributes to the propagation of the fire.

The heat given off by its combustion proper can permit charcoal to burn completely. This is the case in a stove or a fireplace where the density of combustible is sufficient and the draft well regulated, but it is very rare that an isolated piece of wood of large section, such as a post or beam, burns completely. The carbon layer formed, which is consumed only slowly, protects the piece against the penetration of heat and partially isolates it from contact with oxygen. When the ambient temperature decreases, the flames are extinguished and the incandescence ceases progressively.

*

* *

The course of the phenomena of combustion constitutes the reaction to fire. The reaction of wood to fire is positive, contrary to that of stone, of brick, and of metals having a high melting point. It includes two important elements--the rapidity of initial ignition and the speed of propagation--which one seeks to determine by tests.

Before examining methods of qualification, it is necessary to give an account of their real range because the reaction to fire is by no means a constant characteristic of a material.

Factors influencing the reaction to fire.--It depends first of all on the sample; a veneer or thin sheet of wood does not behave like a plank or beam, and its reaction will be different depending on whether it is free or applied on a support which is noncombustible or nearly so. Similarly, a panel with smooth surface, planed or polished, or even a piece of wood with rounded corners will ignite less easily than a piece rough from the saw with square corners.

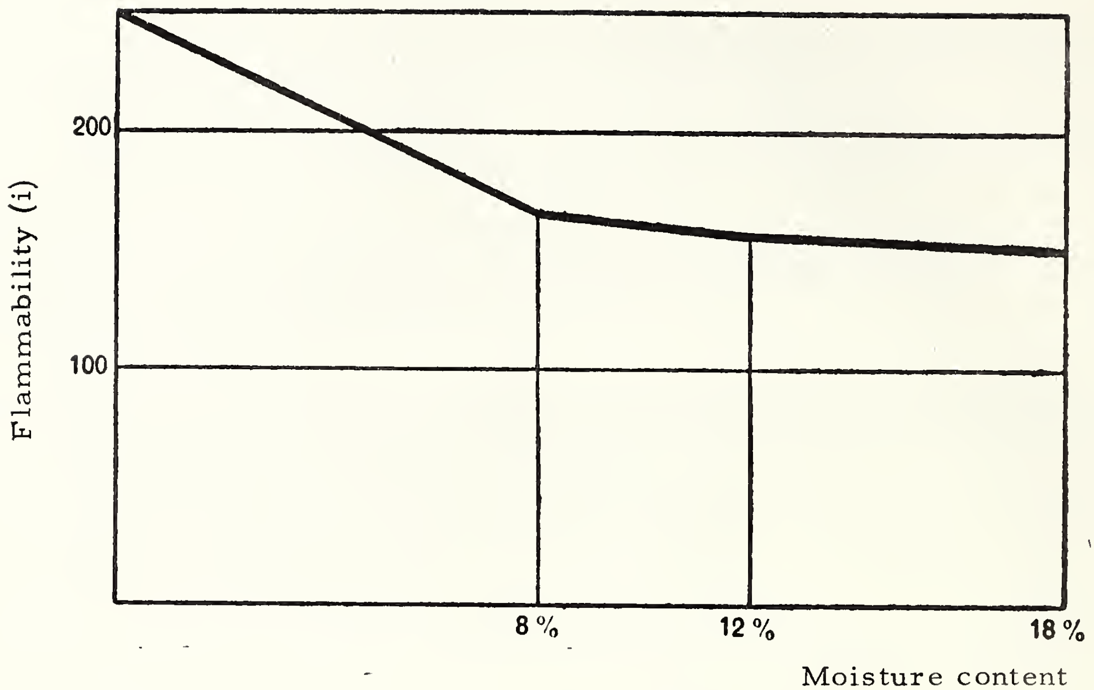
Moisture content also has a great influence, since the vaporization of the water absorbs considerable energy and slows the rise in temperature (fig. 2).

Differences between species of wood are of comparatively less importance for similar densities, except for very resinous woods; but the variations and natural defects (cross grain, knots, splits, or checks, etc.) strongly influence the delay in ignition and especially the propagation of the flame.

--The nature of the source of heat and the conditions in which it acts are also very important. If the source of heat is too weak with respect to the mass of the wood, there will be no ignition (a plank can't be ignited with a match). If it is too strong, as the wood is an insulator, it can be destroyed locally without ignition (one can pierce a plank with a welding torch without igniting it).

--Finally, the supply of oxygen influences the speed of propagation of the flame. Ventilation fans the combustion, but a violent current of cold air can extinguish or cut off a flame (one commonly extinguishes a match by shaking it).

Thus, for each combustible, there is a group of circumstances which favor or thwart the ignition and the spread of flame. In practice, these circumstances rarely all have a harmonious influence and, in addition, differ from one material to another. Under these conditions, experimental determination of the reaction to fire is arbitrary and very difficult to reproduce. Differences between methods of test in different countries well illustrates these difficulties.



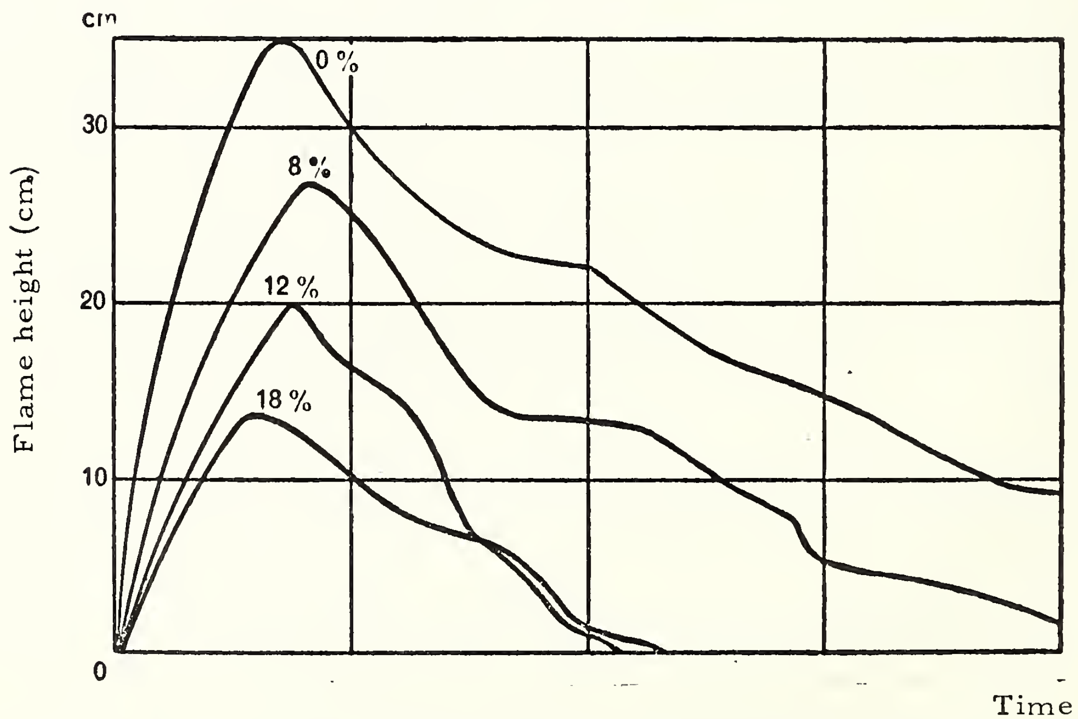


Figure 2.--Influence of moisture content on the reaction to fire (flammability and flame development) of 25-millimeter planed solid oak (according to Gilles). Upper part flammability i vertical and moisture content horizontal. Lower part flame height in cm. vertical, probably time horizontal. Hauteur des flammes = flame height.

2. The French Method of Qualification of Reaction to Fire

(a) Summary description of the method.--It consists of exposing the sample to a source of radiant heat of specific intensity and of inducing ignition of the gases given off.

The apparatus includes[2]:

--The source of radiant heat called an "epiradiator," consisting of a translucent quartz disk heated uniformly by an electric resistance coil (temperature about 800° C.) (fig. 3).

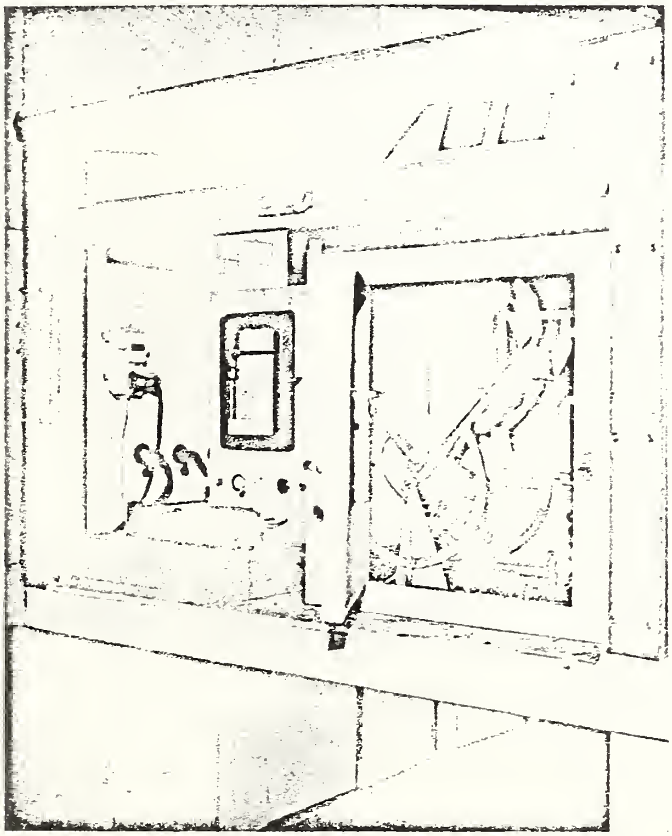


Figure 3.--Epiradiator test. If the epiradiator reproduces rather well the conditions of initial ignition by radiant energy, it does not take account of the behavior of materials under the action of other heat sources nor of their behavior in other phases of a fire.

[2] Decree of the Interior Ministry of December 9, 1957 (Section II, Art. 20) (Official Journal of January 16, 1958).

--Two resistances carried at 1000° C. permitting ignition of the combustible gases on one face or the other.

--A support, maintaining epiradiator and sample in two parallel planes inclined at 45°, at a distance of one from the other (3 centimeters) such that the radiant energy on the sample is about 3 watts per square centimeter per second.

--A chamber having a glass door in which one can establish a specific draft and provided with thermocouples for measuring the temperature of the gaseous mixture going out the flue.

This apparatus is used to determine 4 indices, defined as follows:

--Flammability: $i = \frac{1000}{15t1} + \frac{1000}{15t2}$ (t1 and t2 being the time of ignition measured in seconds on the two faces).

--Development of flames: S (1/140 of the sum of maximum heights, measured in centimeters, attained by the flames each half minute).

--Index of maximum flame height

$$h = \frac{\text{Hcm max}}{20}$$

--Index of combustibility: c = C/120 (C is the area expressed in °Celsius per minute included between the curve of temperature variation during the test and the straight line obtained in operating the apparatus empty).

The values of each of these 4 indices are used to establish the classification of the materials.

(b) Classification of materials according to their reaction to fire (French method)

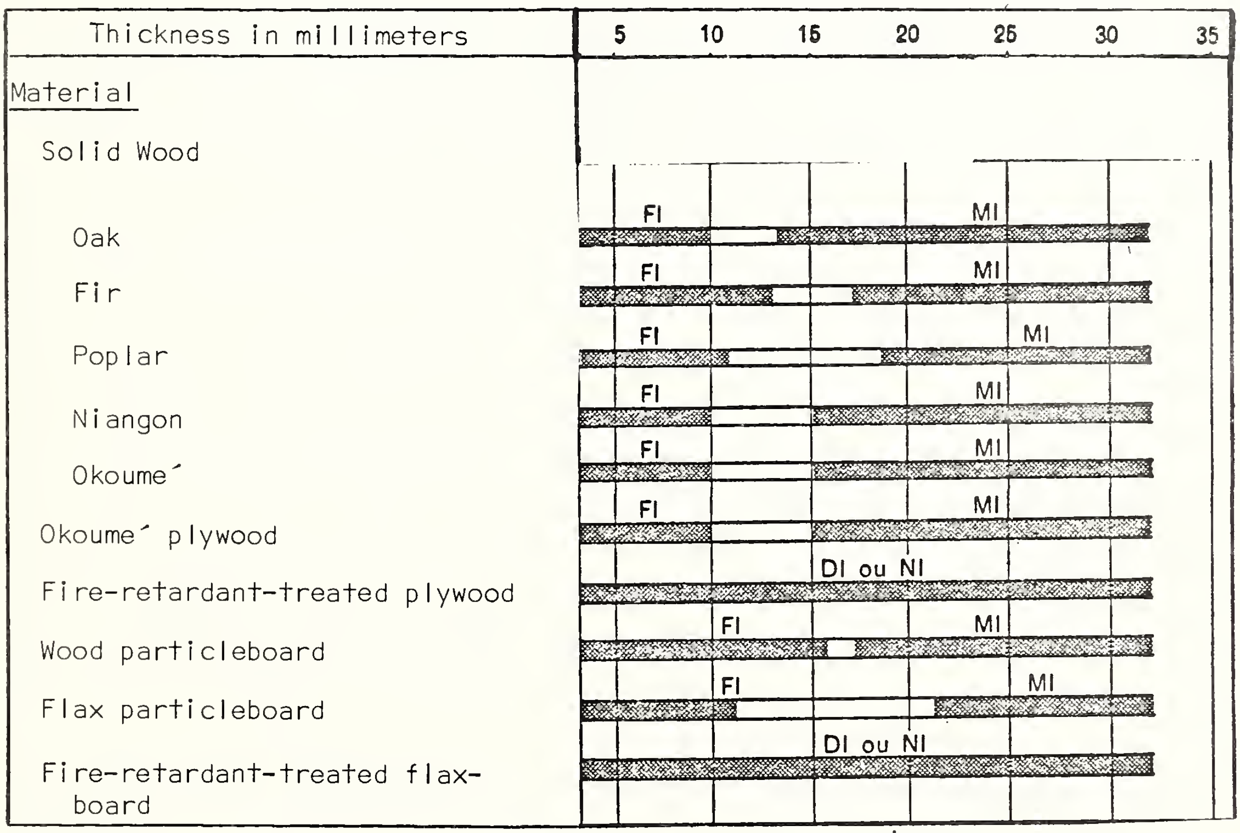
One considers as "incombustibles" materials for which the difference between the lower heat content for a constant volume of raw material and that of the ash is less than 500 calories.

Among other materials which are called "combustibles," the epiradiator test permits distinguishing:

--Nonflammable materials, which do not give any flame (the first three indices are invalid);

--Materials which are difficult, average, and easy to ignite, according to the values of their indices.

The following table reproduces the results obtained in the fire reaction test of small solid wood boards stabilized at 60 percent relative humidity and a temperature of 20° ±1° C.



FI = Easy to ignite
MI = Average ignitability
DI = Difficult to ignite
NI = Non-flammable
(Classification according to the legal test for reaction to fire with an epiradiator)

These results have only an indicative value, at least in the limit zone (marked by a blank), in view of the difficulty of obtaining identical results with the same material under the same conditions.

They must not be used to justify a classification, since this can be obtained only by carrying out the test in an acceptable laboratory.

(c) <u>Observations on the French method of qualification of the reaction to fire</u>

This method is valuable for study and research. It permits comparison of materials of the same nature in the form of samples of identical dimensions. It is useful, for example, for studying the effectiveness of fire-retardant treatments and their improvement.

However, the principle of the classification of materials according to their reaction to fire calls for reservations because--as has been indicated above--this is not a constant characteristic of a given material. It depends on the dimensions of the sample and the results are widely scattered, even for a sample of the same characteristics.

In addition, the interpretation of the results is carried out with a very arbitrary scale and sometimes leads to illogical classifications.

CHAPTER II

FIRE-RETARDANT TREATMENT

Wood being of organic origin and composed essentially of carbohydrates, it cannot be rendered indestructible by fire. But there exist some procedures permitting reduction of its flammability and, in more general fashion, of retarding its destruction.

The practice of fire-retardant treatment of wood goes back to antiquity; alum was used then or the pieces to be protected were covered with a layer of clay. The first complete study on fire-retardant treatment is due to Gay-Lussac who, in 1821, set forth the principle and mentioned some chemical products still considered today as the most effective. Currently, intensive study of combustion permits understanding in part the mechanism of the action of fire-retardants and suggests new procedures for treatment.

First of all, without any modification of the composition of the wood, its ignition and its destruction can be retarded by protecting it against the action of heat with a screen. This can be formed by an incombustible material, a thermal insulator, or a simple barrier against convection

currents or thermal radiation (mineral wool, asbestos fiber-cement, etc.). It can also consist of a layer of heat-absorbing material like plaster.[1] Finally, it can consist of a bright polished surface which reflects the radiant energy. Sometimes also, local temperature elevations can be resisted by arranging, at the surface of the wood or as a sublayer under a thin veneer, a metallic sheet which, as a good heat conductor, disperses the heat applied at a point.

But we will not give to these various means of combating fire the name of fire-retardant processes. We will reserve this expression only for those techniques which, modifying the composition of the wood as a mass or by surface application, act essentially by a chemical process.[2]

1. Mode of Action of Fire-Retardant Products

Recent discoveries and hypotheses show that the action of fire retardants is much more complex than was supposed a few years ago. In a study of the fire-retardant treatment of materials[3] Mr. L. Amy, Chief Engineer of the Municipal Laboratory of Paris has stated the different processes on which rest the effectiveness of these products:

--Elevation of the temperature of thermal decomposition of the basic constituents of wood (cellulose and lignin);

--modification of their mode of decomposition, with reduction or delay of the release of combustible gases (inhibition of incandescence);

--inhibition or delay of the combustion in the gaseous phase by the action of anti-oxidants or by the dilution of the combustible gases;

--mechanical obstacle to the mixture of the gases of decomposition with air.

---

[1] Plaster, in a thickness of 1 centimeter or more is an excellent heat absorber because of its water-retention energy. It can be reinforced with a metallic grid or applied to wood pierced by nails with large countersunk heads.

[2] This distinction is not absolute, the effectiveness of certain of these treatments being explained in part by a physical mechanism. Nevertheless, it is rare that the development of combustion reactions is not found to be modified.

[3] Published by the magazine PACT-Brussels.

It is necessary to bring out that, with their principal mode of action associated with one of the categories above, certain fire retardants associate a secondary action, like the formation of a thermal insulating layer or the absorption of heat for their decomposition, or by the vaporization of the water which they retain. The most important factor in this secondary action is certainly water, whose evaporation absorbs considerable energy and whose presence retards the elevation of temperature beyond 100° C.[4]

(a) Elevation of the temperature of decomposition.--Certain substances render organic compounds more stable to heat. Their degradation being retarded, the emission of combustible gases and, consequently, the ignition, occurs only at a higher temperature.

Information on the mechanism of this action is poor; it is accepted that there is a substitution in the intermolecular linkages which unite the cellulosic chains.

This role can be played by the groups -OH, = O, $-NH_2$, present in the fire-retardant products (notably sulfates, sulfamates, and phosphates). These products are strongly hygroscopic and would tend to assure the equilibrium of their electrostatic charge by their linkage with the hydroxyl groups of the cellulose in the absence of molecules of water.[5] Mr. Amy recalls that one can find in the electron theory of Lewis on the acceptors of electrons an explanation of the role of strong acids and bases. But, rightly, it emphasizes that catalytic dehydration is only a manifestation of the action of hydrogen-bonding groups and not an explanation of their effectiveness. According to him, this would have to be sought in a condensation of organic molecules in a more stable structure, a phenomenon analogous to that which is observed when, by the mixture of several volatile and combustible organic compounds, one obtains nonflammable polymers.[6]

(b) Modifications of the chemical process of destruction of lignocellulosic compounds.--It is possible to modify the course of the chain of reactions occurring during the pyrolytic destruction of cellulose in such a way that it will no longer produce inflammable gases or tar. There is thus a very effective means for impeding the ignition of wood and retarding its destruction.

---

[4] Practically all the fire retardants with chemical action are strongly hygroscopic, and wood fire-retardant treated by impregnation has a higher moisture content in the same atmosphere than that of nontreated wood. One has seen (Chapter I, page 4) the considerable influence of the moisture content of wood on its reaction to fire.

[5] Hypothesis brought out, notably, by F. L. Browne in Report No. 2136 of the Forest Products Laboratory, Madison, Wis.

[6] Article already cited.

Fire-retardant salts frequently include a strong acid or base combined with a weak base or acid or, more generally, are dissociable at a temperature below the carbonization threshold of wood (chlorides, ammonium sulfates and phosphates, borax and sodium carbonate, zinc chloride or aluminum chloride). Salts of a strong base and acid like sodium chloride, sodium sulfate, or sodium phosphates are without effect.

In another way, the oxidants like potassium nitrate, the metallic chromates, and potassium permanganate, are relatively effective, although for the most part they cannot be used because they attack cold wood.[7]

One is thus led to think that fire retardants induce the carbonization of wood at a temperature below the ignition threshold. A large part of the carbon is thus transformed into charcoal before distillation or thermal decomposition occurs which, in untreated wood, is indicated by the emission of combustible gases and the formation of tar. When the temperature attains the ignition threshold of untreated wood, this emission can no longer occur and the fire-retardant-treated wood does not ignite.

One ascertains in fact that all the fire retardants bring with them an increased yield of charcoal during carbonization in a retort (25 to 50 percent more). The quantity of water vapor produced would similarly be greater.

A theory has been proposed to explain the action of strong acids by the formation of stable esters which check the process of decomposition of cellulose. This esterification of the alcohol functions is carried out with elimination of water and it "blocks" the advent of volatile and combustible or easily dissociable organic compounds of gaseous hydrocarbons and carbon monoxide, a normal stage of the pyrolytic decomposition of cellulose (glycolic, lactic, acetic, and formic acids).[8]

The esters are decomposed later beyond the ignition threshold, giving water and carbon directly without the appearance of intermediate organic compounds, and regenerate the acid.

However it may be, the identity of the mode of action of the fire retardants, ammonium salts or easily dissociable metallic salts of zinc and aluminum, appears to be demonstrated by the addition of their action when they are used in mixture.

On the contrary, the derivatives of boron, of antimony, of arsenic, and of tin cannot be partially substituted for the salts of the first category without

---

[7] This observation applies also to strong acids and bases, sulfuric acid or caustic soda.

[8] See 5, F. L. Browne, R2136, already cited.

occurrence of a significant decline in the fire-retardant power of the mixture used in equal weights. Mr. Amy cites, in the article already mentioned, the influence of an addition, to 50 percent of the mixture, of a borax-boric acid preparation to ammonium sulfate. However, used alone, the derivatives of boron, antimony, arsenic, and tin have an inhibiting power fully as great as that of ammonium or metallic salts. They apparently have the same action increase in the production of charcoal and of water vapor to the detriment of the formation of combustible gases and of tar. Thus it must be admitted that these results are obtained by a process other than the esterification mentioned above for the acids. Mr. L. Amy conjectures that the boron, antimony, or arsenic ions react on two alcohol functions carried by the neighboring carbons of a single cellulosic molecule. The action of sodium borate on certain natural noncyclic polyalcohols (mannitols) is an example of such condensation. This combination, unstable to heat, would furnish the point of attack on the cellulosic chains by which the process of destruction would be set off at a temperature below the ignition threshold.

Lignin appears to undergo, under the action of fire retardants, a transformation analogous to that of cellulose. However, small quantities of fire-retardant products first induce, paradoxically, an increase in flammability. This can be explained by the formation of methyl alcohol at the expense of the oxy-methylene groups. A larger quantity of fire retardant induces the inhibition of the combustion of the methyl alcohol by the other products of decomposition.[9]

--Total combustion implies also the oxidation of the carbon and the destruction of the charcoal (incandescence).

This second phase, which occurs in proportion to the formation of charcoal, is very important to consider. It gives off a large part of the total heat of combustion (about 40 percent), and it is the persistence of the incandescence which determines in part the extension of the initial source and especially the difficulty of its definite extinction.

Among the fire-retardant substances inhibiting ignition which have been examined above, certain of them reduce the incandescence of charcoal, which is the case with the ammonium phosphates. Others do not influence it in a sensible way (borax, arsenate, aluminum chloride, ammonium sulfate); certain favor it (chromic acid, chromium chloride, manganese, cobalt, and copper). Conversely, the substances which limit incandescence, like boric acid or ammonium borate, do not affect ignition.

Some physical theories have been advanced to explain the action of incandescenc inhibitors which form by their fusion an insulating layer preventing contact of

[9] L. Amy, article already cited.

oxygen with the charcoal. These theories are contested and, besides, they do not take into account the anti-incandescent action of the ammonium phosphates which are not thought to form such coverings, which is why the chemical explanation appears more true. Fire-retardant substances endowed with incandescence-inhibiting properties act as catalysts in the combustion of carbon. They would increase the production of carbon monoxide to the detriment of the carbon dioxide (increase of the ratio CO/CO_2). The course of the combustion is found to be modified because the amount of heat is greatly reduced (-68kC per molecule).

$$C + 1/2\ O_2 = CO + 26.43\text{kC per molecule}$$

$$CO + 1/2\ O_2 = CO_2 + 67.96\text{kC per molecule}$$

This explanation appears probable when one remarks that not only is the inhibition of incandescence characteristic of certain atoms (P, Br, Cl, etc.) in the substances where they are easily liberated, but the proportion of active product can be much lower than that which prevents ignition. It is thus that monoammonium phosphate is active against incandescence in a proportion of 0.5 percent, although inhibition of ignition is effective only for proportions on the order of 10 to 20 percent.

This catalytic action occurring beyond the temperature corresponding to the threshold of ignition, one conceives that one can combine an ignition inhibitor such as borax with an incandescence retarder such as boric acid.

(c) Inhibition of the combustion in the gaseous phase.--It is known that a mixture of air and combustible gases can ignite only if the proportions fall within limits which vary with temperature and pressure. The addition of inert gases can prevent ignition.

In order for the inert gases emitted by the fire retardants to prevent ignition, it would be necessary that the fire retardants be in very considerable quantity. One kilogram of wood can, in fact, give rise to 140 to 150 liters of combustible gas and the volume of the mixture with air susceptible to burning attains 300 to 3,000 liters depending upon the proportion of the mixture which is of combustible products. Thus at least 150 liters of inert gas is necessary and most frequently much more. Diammonium phosphate, for example, can give off only 44.8 liters of ammonia per gram-molecule; there would thus be necessary, at a minimum, more than 1 kilogram of salt per kilogram of wood, a concentration which it is impossible to attain.

Nature of flammable gas	Limiting concentrations in air (percent of the volume of the mixture)	Minimum of diluent gas to render the mixture non-flammable in all proportions (percent of the volume of the entire mixture)	
		H_2O	CO_2
H_2	6 -72		
CO	12.5-77	54	52
CH_4	5.3-16	29	24
C_2H_6	3.0-12.5	--	33
C_2H_4	3.1-32.0	--	40

Ammonia, like water vapor, can however, if not totally inhibit the combustion of burning gas, at least retard the violence of this combustion. But the principal diluent, perhaps, consists of the products of combustion of the wood, water vapor and carbon dioxide, which represent--under certain conditions--nearly half of the gaseous volume given off.

Certain fire retardants, notably those containing halogens, can act in a manner quite different and much more effective. By a catalytic action which regenerates them in proportion, they render impossible the combination of oxygen and the combustible gaseous products. Thus, by adding 6.2 percent of methyl bromide or 2 percent of carbon tetrachloride to a mixture of carbon monoxide and air, one prevents its combustion, whatever the proportions, although it would require 54 percent of water vapor or 52 percent of carbonic anhydride to obtain this result.

This appears to be explained by the fact that the diluents act only to reduce the frequency of the collisions between the molecules and the free radicals, which bring on the combustion in the gaseous phase without breaking the chain of these reactions. Inhibitors like the halogens, on the contrary, break this chain. At combustion temperatures, their molecules, dissociated into atoms, are combined with the essential radicals of the combustion upon which the new combination gives rise to more or less inert products, less reactive, and regenerates the halogen.

$$HCO + Br \qquad HBr + CO$$

$$OH + HBr \qquad Br + H_2O$$

An anti-oxidant role is sometimes attributed to ammonia and water vapor.

(d) Obstacle to the mixture of decomposition gases with air.--It is evident that in the absence of air, not only can the ignition of combustible gases not occur, but the whole combustion process is modified since oxidation is no longer possible.

Certain mixtures of fire-retardant salts fuse at a temperature below that at which active pyrolytic decomposition of the wood begins, forming by this fusion a layer protecting the material from contact with air (sodium silicate, borax-boric acid mixture). But the products which, at these same temperatures, form stable foams (intumescent products) give insulating barriers infinitely better and more durable. It is known that the effectiveness of these products[10] is reinforced by the thermal insulation provided by the layer of foam.

However, it is necessary to observe that, in its active phase, pyrolytic decomposition gives rise to a considerable volume of gas (2 liters per gram of wood at 12 percent moisture content at 600° C.). Enormous pressures would result from this if the insulating layer could not deform. It is observed, for example, that certain ordinary paints or varnishes act but little as insulators, and that the most flexible ones are the best, the hard varnishes and lacquers cracking very rapidly. The imprisoned gases which are formed--notably the tars--can diffuse into the cooler zones where they are condensed. The evolution of the combustion is modified, and there is produced a greater quantity of charcoal and of water vapor.

It is interesting to note that it is by an analogous mechanism that a thick panel or a piece of wood of large cross section naturally resists fire well. The carbonaceous layer which is formed, and in which the tars have played the role of intumescents, protects the internal zones at the same time both against heat and against contact with the air. The gases and tars which are formed at the limit of the layer undergoing combustion migrate toward the cooler interior of the piece, where they condense. It is more difficult to ignite anew a piece of wood already partly burned and extinguished some time before, because it is thus somewhat fire retardant.

---

[10] Among the intumescent agents are the mineral salts (alkaline carbonates, ammonium phosphates), natural organic products (starch, casein) or synthetic organic products (paraformaldehyde, urea, aminoacetic acid, etc.).

2. Procedures For Fire-Retardant Treatment of Wood

It has already been indicated that fire-retardant treatment, properly speaking, can be carried out in two ways: either by incorporation of fire-retardant salts in the mass of the wood or by surface application of fire-retardant products.[11]

(a) Deep fire-retardant treatment.--Wood being a porous material, it is possible to introduce solutions of fire-retardant products into it. After evaporation of the water, the fire-retardant salts remain in the interior of the wood. The effectiveness of the protection depends greatly on the quantity of the product incorporated. The reaction to fire can be profoundly modified (classification--difficult to ignite or nonflammable) only by large proportions of salts (35 to 80 kg. per meter^3).

This treatment of solid wood can theoretically be carried out only in an autoclave by initial vacuum and injection under pressure. Despite this the impregnation is generally not complete because the vacuum leaves a certain quantity of air in the wood, and in the following operation this air will remain compressed within the piece of wood preventing the solution from reaching this region. In addition, the ease of impregnation differs greatly with the species of wood, as well as between heartwood and sapwood. Thus, whatever the conditions involved--increase of vacuum, increase in pressure, elevation of temperature and of concentration of the solution--one can not obtain equal impregnation in the whole mass of the wood.

For easily impregnated species (beech, poplar, etc.) and for thin elements or pieces of small section, one can obtain a sufficient absorption of fire-retardant salts by simple soaking in a hot-cold bath or even in a hot or cold solution.

The products used are the salts mentioned earlier as fire retardants, generally used in mixture and, commercially there are mixtures of appropriate composition.[12]

Solid wood is not alone in being suitable for these treatment processes; wood-based materials can also be impregnated with fire-retardant products, but

[11] Independently of coating by materials used in considerable thickness, such as plaster, or the application of sheets or panels designed to protect the wood from heat or direct contact with flame.

[12] It is recalled that there exists a label issued by the Technical Group for fire retardant treatment. This label extends also to the treated material.

the peculiarities of structure or of fabrication sometimes make impregnation difficult or impossible without deterioration.

That is, the gluelines are an obstacle to the diffusion of the salts, and that the water of the fire-retardant solution can deteriorate certain types of panels.

For plywood, the veneers are generally treated before drying by soaking in the solution of fire-retardant salts (most frequently mono and diammonium phosphate in mixture). It is, of course, necessary that the products retained by the wood do not interfere with gluing quality.

For particle boards, the treatment is carried out by spraying the solution on the wood particles before drying. Compatibility with the binder must be verified.

Finally, for fiberboards, fire-retardant treatment is much more difficult to carry out, because these materials being wet-formed, it is important to carry out a precipitation of the retardant on the wood fibers and an insolubilization to avoid their being carried off by the water. Sometimes the treatment is carried out on the final product by filtering the solution through the panel, but this requires, naturally, a redrying.

(b) Surface fire-retardant treatment (paints or varnishes).--This is a matter of applying on the surface of the material to be protected a layer of fire-retardant product. Penetration in the wood is small, just sufficient to cause bonding.[13]

It is thus the behavior in fire of this layer itself which determines the efficacy of the treatment. The procedure is obviously much less difficult than impregnation and permits in-place treatment of wood and of wood-based materials. On the other hand, one can assure protection, apart from any question of aging, only if the treated wood is protected against the action of water or moisture and if it is not leached or scratched or painted later with a nonretardant product.

Fire-retardant paints and varnishes include essentially the same chemical compounds as do the solutions used for impregnation. But it is clear that their concentration in the protective layer must be quite high and that this

[13] One can also apply to the surface solutions of fire-retardant salts currently used for deep impregnation but in much stronger concentration. There is then a certain penetration in the wood. But by reason of migration of the fire-retardant salts, it is very difficult thus to obtain a durable, effective protection. On the other hand, the action of moisture rapidly suppresses any fire-retardant effect, unless the wood is later varnished.

layer itself must be thick. The amount of fire-retardant paints or varnishes of normal type are of the order of 800 grams to 1 kilogram per square meter. The appearance of intumescent products has permitted lowering the amounts to a few hundred grams per square meter.

The diversity of chemical products used in a single formula renders any classification impossible. Only the phenomenon of intumescence permits establishing a distinction, which is not absolute.

Nonintumescent Paints and Varnishes

These are the standard fire-retardant paints and varnishes. They involve a very different number and proportion of active products, depending upon their specialties. Certain are compounded to produce, by fusion, an insulating layer which essentially prevents and retards incandescence. They are based on borates and boric acid, silicates, and antimony oxide. Others have been prepared to combat initial flaming and to retard the development and spread of flames. They act essentially on the chemical process of combustion and sometimes can contain up to 10 different chemical compounds.

Intumescent Paints and Varnishes

This very interesting property was accidentally discovered in the United States. A chemist studying, in the laboratory, the protection of fabrics against decay and weather one day spilled a flask of solution on a fiberboard. Some days later a Bunsen burner accidentally set fire to the panel. The chemist was astonished and interested to observe the flames stop at the edge of the spot left by the solution and that a sort of sponge was raised on the spot, protecting the panel.

Thus was intumescence discovered. Its effect today permits a significant reduction in the thickness of the layer of fire-retardant paint.

An intumescent paint involves a substance which, decomposing under the action of heat with emission of inert gases, forms a foam whose thickness can reach several centimeters. To the intumescent product proper[14] are added some thermosetting synthetic resins (epoxies and silicones) in order that the foam formed will harden and resist carbonization for a rather long time.

---

[14] See page 19.

Finally, there is frequently associated with them some standard fire-retardant products, notably boric acid, which forms a glassy film on the foam.

3. Advantages and Disadvantages of Fire-Retardant Treatment of Wood

It is necessary to consider fire-retardant treatments both from the point of view of their effectiveness and of the modifications which they can cause in the characteristics of the materials and in their cost.

(a) Durability of the protection.--Deep impregnation gives very durable results, even when the treated woods are exposed to water, moisture, and weather. Experience with woods treated for marine or mine use goes back 150 years. One observes only that decay is favored by the treatment, but this is easily remedied by the addition of fluorides.

On the contrary, fire-retardant paints of traditional type generally have a very temporary effect. They lose their fire-retardant qualities very rapidly, as has been confirmed by experiments carried out some years ago.[15] Among the principal causes of this aging is the action of carbon dioxide in the air, which displaces the silica of the silicates.

Besides, practically all of the fire-retardant varnishes and paints do not resist wetting and must not be exposed to the weather. Some improvement seems possible by the application of chlorinated rubber paints on a fire-retardant paint used as an undercoat.

(b) Modification of the characteristics of the treated materials.--Although the most important quality of a fire-retardant treatment is its effectiveness, it is also clear that it must not alter the characteristics of the material to which it is applied. But impregnation with fire-retardant salts makes the wood strongly hygroscopic, somewhat corrosive in contact with metals, and from the point of view of its application, more abrasive to tools and more difficult to paint or to varnish.

Most of those disadvantages do not exist when fire-retardancy is accomplished by paint or varnish. But then they have surface qualities (ease of maintenance, possibility of washing) and appearance which are affected.

---

[15] Tests carried out at the C.T.B. in 1959 on nine commercial fire-retardant paints.

Fire-retardant paints do not possess the full range of colors of current products, and the preparation of various shades by mixture or by supplementary pigmentation is difficult. Certain products change color, notably those containing silicates or those which are not neutral.

There have been efforts to improve surface appearance by the application over the fire-retardant paint of a layer of ordinary paint, but the products used must be nonflammable and must adhere well without reacting on the fire-retardant paint.

As to fire-retardant varnishes, they do not currently give satisfaction from the esthetic point of view.

(c) Cost.--The cost of fire-retardant treatment can limit the use of treated wood. Deep impregnation carried out in a retort is very costly (50 to 80 percent of the cost of the wood), which seriously reduces its utilization. Multiplication of treatment stations, the direct sale of fire-retardant wood, and the practice of simple soaking when it is effective would probably permit it to become more competitive. Nevertheless, it appears probable that, for all current applications of solid wood, fire-retardant treatment, which does not sensibly increase the duration of resistance to fire, is an impractical costly operation.[16]

Impregnation presents much more interest for thin panels, but its cost and the disadvantages shown by fire-retardant-treated panels frequently make it preferable to use other conditions for rendering the material less flammable such as gluing on an incombustible base.

Fire-retardant treatment by painting has a much more acceptable cost, although intumescent paints are costly (around twice the price of ordinary fire-retardant paints), but the objections to the use of these paints are principally related to esthetics.

This rapid examination of fire-retardant procedures shows that there are available today effective means for improving the behavior of wood in fire.

Nevertheless, the numerous problems in the use of fire-retardant wood and the cost currently render generalized use impossible. It is probable that very substantial progress can still be accomplished in this area and will permit greater recourse to fire-retardant treatment for thin elements, coverings, and partitions, which constitute one of the most imteresting

[16] It is quite otherwise for certain coverings with inert materials (plaster, asbestos, mica, etc.) which permit constituting, with the wood, structures whose fire resistance conforms to regulations.

techniques for the use of wood, both by its cost and by the rapidity of construction, the comfort and the agreeable esthetics which result.

CHAPTER III

DEVELOPMENT OF FIRE

1. Formation of the Initial Source

Ignition of wood can result only from substantial and prolonged heating. This is most frequently induced by the combustion of more flammable substances (paper, fabric, gasoline, etc.), but it can also be the result of radiation or of thermal conduction, of lightning, or even have a mechanical cause (rubbing).

It is rare that a wood building is the origin of a disaster. In 1961 in the Department of the Seine, less than a quarter of the fires can be attributed to the probable initial ignition of a structural element. On the contrary, nearly half are chargeable to the combustion of building contents. One may note also the very high frequency (66 percent) of fires due to some imprudence or negligence.[1]

The initial source results from the combustion of one or several materials whose heat content is considerable. The heat given off is sufficient not only to assure the total combustion of these first fire feeders, but also to bring the other materials, in their turn, to the ignition temperature. At this stage, the heat given off is transmitted by convection, the flame and the hot gases "licking" the exposed surfaces.

The ease of ignition of wood depends upon its species, its thickness, and the condition of its surface. If the heat initially given off is insufficient, the combustion stops by itself. This is what occurs when the starting fire finds only some pieces of millwork or framing of hard wood and of large section.

---

[1] Statistics from the operations of the Regiment of Fire Fighters during the year 1961. It is more difficult to use the general statistics of the Interior Ministry for France, because it is necessary to separate all the disasters which do not have their origin in the construction. It can be said, however, that the fires having their origin in the building contents appear to be 1-1/2 times more numerous than those which can be attributed to initial ignition of an element of construction.

If, on the contrary, the source produces enough heat to induce free ignition of the more flammable wood elements these will continue to burn, even after exhaustion of the initial source, because the temperature is then maintained by the heat of combustion. This heat induces extension of the fire.

With the development of flames, the thermal radiation becomes more intense and there occurs a moment where, as a consequence of the general heating of the enclosure where the fire started, all the combustible substances still spared ignite spontaneously and burn very violently. This explosion of the fire, or "flash-over," occurs after a time variable with the activity of the source, the nature of the materials exposed to radiation, and the ambient temperature. This delay is of 7 or 8 minutes in the most unfavorable cases and can reach 15 or 20 minutes after the moment where the fire has caught openly and vigorously.

The course of a disaster is influenced by the "quality" of the combustibles which the fire finds in its reach--that is to say, in the first place by their heat content. Of all the combustible materials used in construction, wood is not the one which produces the most heat in burning. Certain natural or synthetic products currently used in trim and decoration, such as rubber, vinyl chloride, polystyrene, etc., are much more energy-producing and frequently contribute more than wood to the elevation of the temperature of the initial source. On the other hand, substances frequently stored in buildings like oil, benzene, gasoline, petroleum, etc. are, themselves, endowed with a heat content 3 or 4 times higher. It must no longer be forgotten that, in this first phase, wood remains some instants at the threshold of its ignition temperature. Its combustion is slow, and heat is given off only progressively. It is quite different with very thin materials like paper, fabric, and plastic materials and still more for the flammable liquids, all of whose energy is liberated in a few minutes. The heating is then so abrupt that the thermal losses scarely limit the temperature reached, and there is much greater risk of extension of the fire.

2. Extension of the Fire

Beginning with the initial source, the extension of the fire occurs in several ways simultaneously which must be stated precisely in order to evaluate the behavior of wood during a fire.

(a) Thermal radiation from the initial source, emitted by the flames and by the incandescent materials. The intensity of the radiation is a function of the temperature of the source, which depends, in turn, on the calorific power of the first feeders of the fire, on their rate of combustion, and on the thermal losses other than radiation.

Thermal radiation can set fire to the source from a distance, but in the first phase of the fire its action is limited to the location where the fire started. It is this which, at the end of a certain time, causes generalized ignition.

(b) Convection is the transport of heat by the heated air and gases, even flames. Convection is the principal factor in the initial extension of the source by contact of the flame with a rapidly increasing surface of the combustible material. It permits the fire to progress very rapidly toward the top of a vertical surface and to jump over separations. When the fire has partially destroyed the partitions, notably the glassed surfaces and the doors, convection can cause the appearance of secondary sources.

The magnitude of convection movements thus depends not only on the temperature of the source and on the arrangement of the locale of the fire but also on the fire resistance of the structure.

(c) Thermal conduction is never the cause of the appearance of secondary sources, but it is responsible for the extension of the fire throughout the mass of the combustible attacked, notably in its thickness.

It can be involved indirectly in the transmission over a distance of degradation and destruction which heating can cause in all the elements of construction, combustible or not.

(d) Mechanical transmission is manifested by the falling or projection of incandescent fragments or the carrying of flaming particles by the hot gases. It can also occur by the softening or flowing of hot products.

3. Temperature Reached During a Fire

During a fire, the temperature increases progressively at first. Experience shows that, for a given calorific load, the course of the curve representing this variation is essentially constant. One accepts a type-curve corresponding to a calorific load estimated at 50 kilograms of air-dry wood per square meter of floor (about 217,000 kC/m^2) (fig. 4).

This curve is accepted with very little variation in all countries. In France there has been adopted[2] the graphic representation of the function:

$$T - T_o = 345 \log_{10} (8t + 1)$$

$T - T_o$: temperature rise, °C.

t : time in minutes

[2] Decree of the Ministry of the Interior of January 5, 1959.

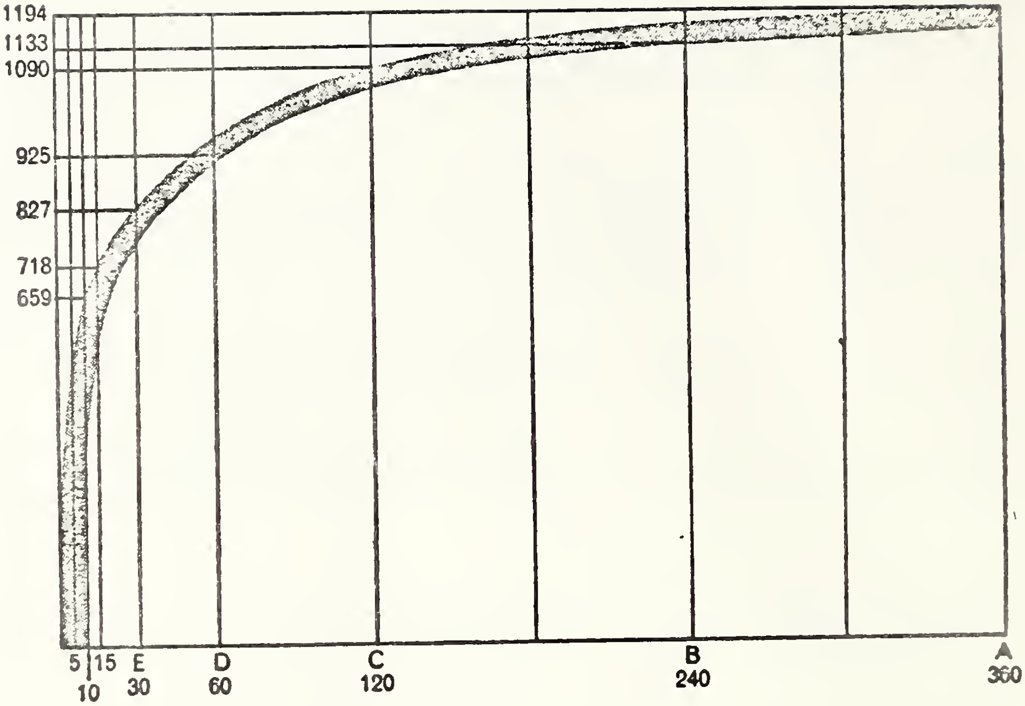


Figure 4. --Time-temperature curve for a calorific load equivalent to 50 kilograms of dry wood per square meter.

This corresponds to the following progression of temperatures:

10 min.	659° C.	1-1/2 hrs.	986° C.
15 min.	718° C.	2 hrs.	1030° C.
		3 hrs.	1090° C.
30 min.	827° C.	4 hrs.	1133° C.
60 min.	925° C.	6 hrs.	1194° C.

It must not be forgotten that the calorific load which controls the course of the temperature variation is represented not only by the elements of construction but by the assembly of all the materials contained in the building. The share of the wood in the building structure is generally small or very small in a modern multi-family building compared to that of furniture, rugs, hangings, cloth, papers, etc. According to American estimates cited by Prof. Franz Kollmann, the calorific loads would be divided as follows in the living places:

	Construction	Other	Total
Bedroom	26	24	50
Library	40	140	180
Office	30	170	200

(in equivalent kilograms of dry wood per square meter.)

It does not seem that, currently, for an apartment of three or four rooms in a modern multi-family building, the amount of wood used in construction exceeds 15 to 16 kilograms/meter^2 on the average, which is little compared with the weight of combustible materials stored in this apartment (25 kilograms/meter^2 at a minimum).

4. Recommendations for the Use of Wood and Wood-Based Materials in Construction

This analysis of the conditions of development of a fire shows that a material of construction affects the development of the fire by its flammability and rate of combustion, its calorific power, the ease with which it transmits heat, and the time during which it continues to play its role in the construction.

Taking account of these multiple aspects, it is possible to indicate some essential precautions in the use of wood and wood-based materials in construction. These precautions, which consider only the materials and their use without presuming either as to the nature of the structures or the size and the function of the buildings, do not, of course, exempt the user from observation of the proper regulations.[3] They will permit architects and businessmen to conform better when they are applicable and will furnish some directions in cases where no limitation is provided.

(a) Solid wood.--Solid wood, like glued laminated wood, does not ignite easily when it is used in average and large thicknesses. The table on page 11

[3] Establishments receiving the public (Official Journal of September 3, 4, and 5, 1954, special paging 1-75), technical circular of the C.S.T.B. relative to habitations (Report No. 283, December 1958), prescriptions concerning fairs and exhibitions and establishments classed as dangerous.

shows that the classification "average ignitability" is reached for thicknesses varying from 12 to 18 millimeters depending on the species. It can be used in traditional constructions for the main walls (heavy framing and carpentry), millwork, floors, and interior trim.

When a degree of fire resistance is required by the regulations, it is generally possible to satisfy it by using sufficient thicknesses and sections, or by a covering of reinforced plaster. Fire-retardant treatment is provided for only exceptionally.

(b) Thick panels (thickness equal to or greater than 15 or 18 millimeters depending upon their nature).

Blockboard panels, plywoods, or particle boards have essentially the same reaction and the same resistance to fire as solid wood of the same thickness and section.

Their behavior is often superior in structures because they can form panels of large dimensions without joints and because they do not have a tendency to split with drying.

(c) Thin panels (thickness less than 15 or 18 millimeters depending upon their nature) which are of solid wood, blockboard panels, plywood, particle board, or fiberboard can be used in construction without particular precaution only for isolated items of limited dimensions (interior doors, cupboard doors, wardrobe doors, sink cupboards, shelving, etc.). It must be seen to that, for these items, they are not used in immediate proximity to sources of intense heat (stoves, smoke flues, or chimneys).

For structures of large extent or forming a continuous surface (partitions, facing elements, wall or ceiling coverings), thin panels must either be attached in a continuous manner and in direct contact with a support at least "difficult to ignite" or fire-retardant treated throughout or, for interior elements, by painting both faces.

(d) Insulating wood panels of all thicknesses must be used on a large surface only if they are attached in a continuous manner on a noncombustible support. In other cases they must be fire-retardant treated.

The following table summarizes these recommendations, whose application remains subordinate to the requirements of regulations, especially for places of public assemblage, multi-family buildings and, finally, individual homes.

	Framing & carpentry, joists & floors	Isolated items of millwork or interior trim	Partitions, wall & ceiling coverings of large extent		Covering & elements of exterior walls
			Bonded in place	Placed on a grid	
Solid or glued-laminated wood and dense panels[1] of thickness greater than 12 or 18 millimeters depending on species and type.	X	X	X	X	X
Thin panels.		X	X		
Thin panels with surface fire-retardant treatment.		X	X	X	
Panels of thickness less than 15 or 18 millimeters, depending on species and type, fire-retardant treated throughout.		X	X	X	X
Decorative veneers.		X	X		
Insulating panels -not fire-retardant treated		X	X		
Insulating panels -fire-retardant treated		X	X	X	

[1]Minimum density 0.450 for solid wood, plywood and blockboard, 0.500 for particle boards.

IMPORTANT OBSERVATIONS

1. The resistance of a structure to fire depends especially on the care with which assembly and erection are carried out.

2. All elements of large extent must receive no flammable paint or varnish which is likely to spread flame rapidly. It is necessary to abstain from the use of wax-based products, varnish and nitrocellulose or acetocellulose lacquers or those using flaxseed oil, vinyl products, and ordinary polyesters.

Glycerophthalic products and polyurethane can be used, but preference will be given to water-based paints or paints and varnishes based on urea formaldehyde or phenol formaldehyde.

3. Particular attention should be given to the insulation of electrical conduit and to protection against heating by radiation or conduction.

4. No electrical conduits or gas pipe and no heating or smoke ducts can pass behind a covering of wood or wood-base material.

CHAPTER IV

FIRE RESISTANCE OF WOOD STRUCTURES

Fire resistance is considered to be the time during which the elements of construction during the standard test are able to play the role expected of them in the construction from the point of view of safety.[1]

It determines directly the ease of evacuation and of intervention and largely influences the rapidity of extension of the fire by the maintenance or the destruction of partitions.

The fire resistance of a structure naturally depends on the speed of its destruction by combustion, but also on the deterioration to which it can be subjected by the action of heat--these latter can affect both noncombustible and combustible materials.

One conceives that fire resistance varies in inverse proportion to thermal conductivity and directly with the specific heat of the material. The better

[1] Definition of the decree of January 5, 1959, Chapter III, Article 13.

insulator it is and the higher its specific heat, the slower its deterioration and destruction will be.

Of all the current construction materials, wood is the poorest conductor of heat. For this reason, it is frequently adopted to form the interior of doors and of fire-break partitions. It has the advantage of interdicting for a long time the passage of heat to the locale to be protected, although beyond a metal door the temperature rapidly reaches the ignition threshold of combustible materials.

Heat involves also, for materials having large thermal expansion coefficients, sizable deformations inducing either defective functioning of some elements (door and window openings), or of failure or collapse of the construction.

Well-conceived wood structures, with the elements correctly assembled, are, on the contrary, remarkably stable in fire. The shrinkage which accompanies the initial loss of moisture does not carry with it any deterioration. Besides, wood retains completely all its mechanical qualities until it is destroyed by fire.[2] Since this destruction is slow and nearly constant for solid wood pieces (0.7 millimeters per minute in depth), one can determine rather precisely how long a supporting element, post, or framing will last. This evaluation, impossible with any other construction material, permits evacuation of the locales and the intervention of means for combating the fire without fear of sudden collapse.

It is known that solid wood or glued-laminated beams continue to support their load long after collapse of metallic framing or even the failure of reinforced concrete elements (fig. 5).

One thus understands all the importance which is attached to determining, as precisely as possible, the fire resistance of building structures.

Being given the constancy of the evolution of temperature as a function of time for a given calorific load, it is possible to envisage a rather true test. Unification on an international plane has been studied.[3] In France, the details of the test are fixed by the ministerial decree of January 5, 1959.

---

[2] Unit strengths increase in proportion to the drying of the wood at the rate of 4 percent in axial compression and 2 percent in tension and in flexure per percent of moisture lost which, for a time, compensates for the reduction in section caused by surface carbonization.

[3] Committee TC/92(ISO) of the International Standards Organization has already reached accord on the procedure for fire-resistance tests of construction elements.

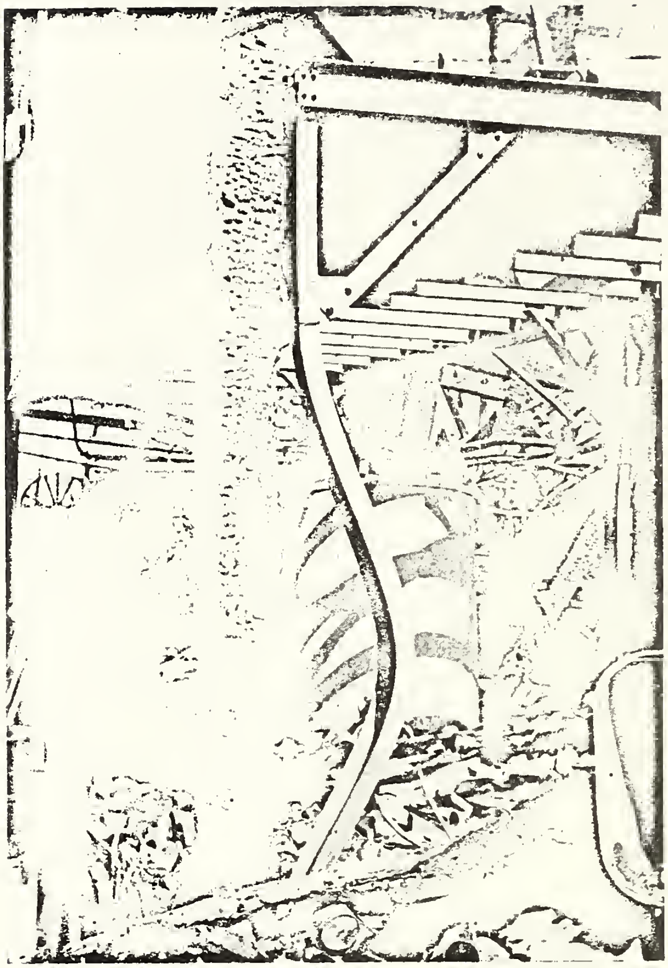


Figure 5.--Fire in soap factory, 200, quai de Clichy, in Clichy, April 13, 1959.

A special furnace is used whose open front face can be closed by the structure to be tested (partition element, door, etc.). On the opposite face a series of gas burners or of fuel oil burners assure heating and their regulation permits following the typical curve of temperature variation (fig. 6).

To test posts or even horizontal elements like beams and floors, special furnaces have been constructed.[4]

The duration of the test is that of the fire resistance claimed for the structure.

---

[4] The C.T.B. has a furnace of the first type permitting testing of elements of reduced dimensions. Experience shows that if the thickness of the section is considered, fire resistances are comparable to those determined with real elements. The C.S.T.B. uses furnaces permitting tests of full-size structures, sometimes loaded.

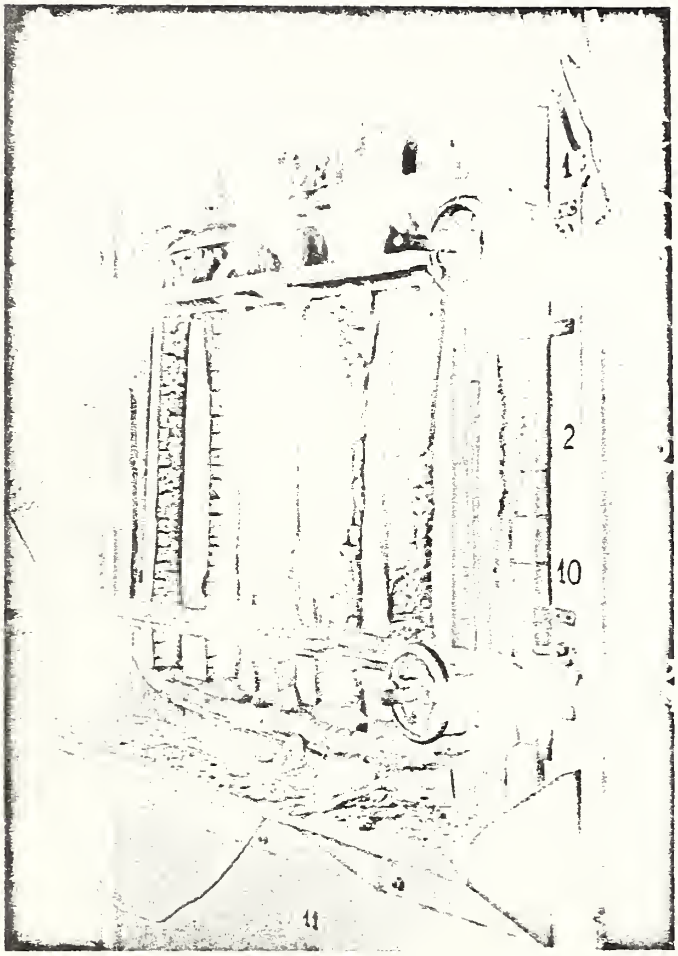


Figure 6.--Comparative test of fire resistance of laminated wood posts.

The categories are the following: 15 minutes, 30 minutes, 1 hour, 1-1/2 hours, 2 hours, 3 hours, 4 hours, 6 hours.[5]

The test is generally continued up to the limit of resistance (maximum 6 hours).

The evaluation criteria are: stability and mechanical strength, thermal insulation (average heating of the unexposed face 140° C., maximum heating 180° C.), flame tightness, emission of flammable gases by the unexposed face.

It is evident that, for posts and framing elements, only the first criterion is valid.

---

[5] The curve of figure 4 permits finding the maximum temperatures corresponding to each of these fire resistances.

If the structure or element to be qualified favorably satisfies all these criteria, it is considered as a "fire break" in the category which corresponds to the duration of the test.[6] If it satisfies all the criteria except thermal insulation, it is considered only as a "flame screen," always in the category corresponding to the duration of the test. If, finally, only the stability of the structure and its mechanical strength are considered, it is called "fire stable" in the category of the duration on the test.

It will be noted that the expressions "fire break," "flame screen," and even "fire stable" applied to a construction have no meaning if they are not accompanied by a precise statement of its fire resistance or, possibly, of the category to which it pertains according to the official classification.

*
* *

Structures of solid wood generally possess good stability to fire. Wood doors, walls, and partitions of suitable thickness are both "flame screens" and "fire breaks" for the same duration. It is established that a covering of thin steel plates brings no particular advantage and tends to reduce, rather than to increase, the fire resistance of these elements. This is due to the high insulating power of wood and to the slowness of its destruction in thickness by fire. But the conditions of manufacture of these structures, their assembly, and erection are very important. The failure of a joint or the formation of a split can abnormally reduce the duration of the resistance of a structure.

These tests, carried out on full-size elements of construction, have great interest in the study and the qualification of elements of construction and permit improvement of the structure. In the matter of prefabricated elements, they show that no guarantee can be given by the builder unless they are accompanied by precise directions and recommendations for erection.

The Centre Technique du Bois has undertaken, in cooperation with the Fire Laboratory (experimental station of the C.S.T.B. at Champs-sur-Marne), a research program on the fire resistance of full-size structures.

Various tests have been carried out at the same laboratory at the request of the Institut de Recherches des Applications du Bois, as well as on elements

---

[6] This category is that of the scale indicated above, which is equal to or immediately below the observed effective duration. For example, if the structure endures for 20 minutes, it is in the 15-minute category of fire resistance.

presented by the manufacturers (glued laminated posts and beams, doors, partitions, etc.).

We will present briefly the results obtained.

Experimental Investigations of the Fire Resistance of Wood Elements

The first tests carried out had for their objective the determination of the degree of resistance of posts and other framing, of both solid wood and glued-laminated wood.

Numerous tests have also been carried out for several years on flush doors and prefabricated partitions at the request of the manufacturers. It is important, in fact, to define for these nontraditional elements the rules of construction assuring them of sufficient fire resistance when this requirement is formulated.

Finally, more recently there was included in the test program some studies on the characteristics of structure and of the conditions of placement which facing panels must satisfy to avoid any risk of transmission of fire from one story to another by the exterior. These studies were carried out both on full-size elements and on experimental assemblies at a reduced scale.

Although the program is not yet completely carried out, the results obtained give some new data which will certainly permit making more flexible, without increased risk, certain provisions of restrictive current regulations counter to wood.

Posts and Beams

The fire resistance of solid wood posts and beams is well known. It is illustrated by the results of tests carried out several years ago at the test station of the C.S.T.B.[7] Oak posts 0.15 by 0.15 by 2.30 meters loaded to 10t showed the following fire resistances:

--bare wood	52 minutes
--with covering of 0.01 meters of reinforced plaster	81 minutes
--with covering of 0.02 meters of reinforced plaster	110 minutes

[7] Report of March 11, 1955.

The comparison between solid posts and glued laminated posts was carried out more recently (1962) at the Centre Technique du Bois (fig. 6).

It is understood that laminated wood is the material formed by the gluing together of layers of wood with the grain direction parallel. The thickness of the layers of wood is not without importance with respect to fire resistance. If the gluing is very resistant, it is preferable to make the laminated wood of thin layers (0.01 meters maximum), which is more stable and whose gluing resists aging better. If, on the other hand, the glue joint is deteriorated by heat, elements with thick layers will be less rapidly destroyed, the delamination and the separation of the layers, which hastens the combustion, occurring less rapidly. It is this, among other things which this test demonstrates, the results of which, after 35 minutes of fire action, are given below.

Sample	Fraction of the section destroyed by fire (fig. 7)
Solid wood control	52%
Laminated wood (10 millimeters) glued with resorcinol	49%
Laminated wood (10 millimeters) glued with casein	63%
Laminated wood (10 millimeters) glued with urea formaldehyde	63%
Laminated wood (17 millimeters) glued with urea formaldehyde[8]	54%

One can thus be assured that glued-laminated wood elements, suitably made, have fire resistance equivalent that of solid wood pieces of the same section.

Resorcinol glues appear to show a special resistance to fire and, from this fact, hold the protective carbonaceous layer more strongly.

Urea-formaldehyde glues, on the other hand, have a tendency to disintegrate under the action of high temperature which induces the beginning of separation of the laminations which favors the progression of fire toward the interior. However, when the lamination thickness is greater than 10 millimeters, this behavior does not reduce the resistance below that of solid wood or of laminated wood glued with casein.

[8] German manufacture.

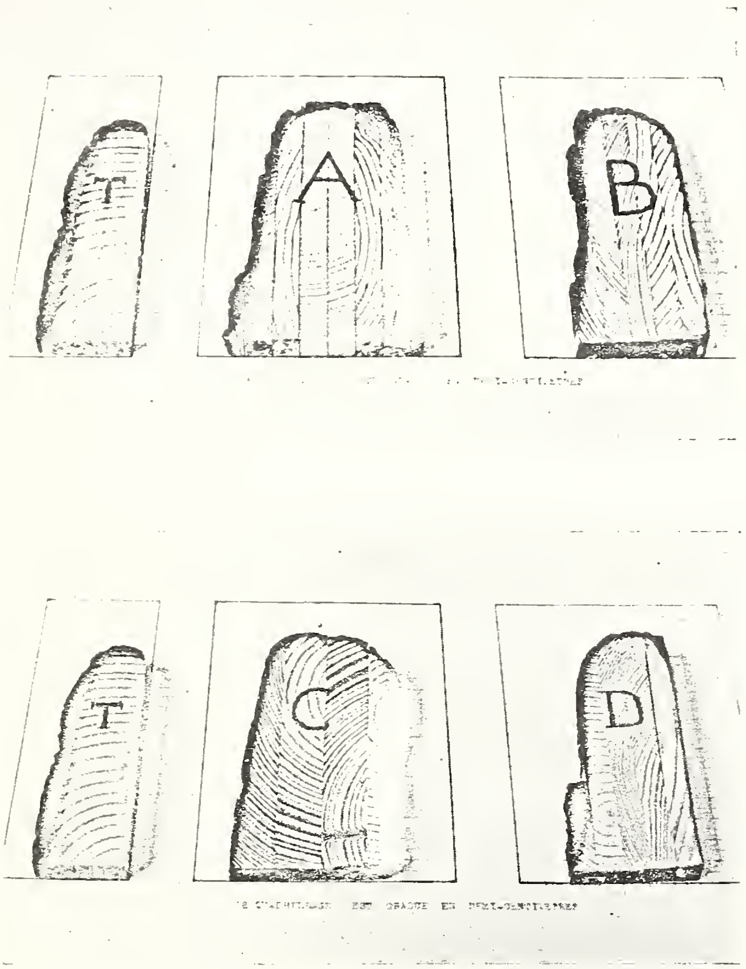


Figure 7.--Sections of posts after tests.

It is evident that glues which do not resist heat (polyvinyl acetate, neoprene, etc.) cannot be utilized.

Doors and Partitions

There are summarized below, in tabular form, an assembly of results concerning the fire resistance of doors and partitions of various types made of wood or other ligno-cellulosic materials. These data were obtained during tests carried out by special request at the Fire Test Station of the C.S.T.B.[9]

[9] The C.S.T.B. has agreed only to deliver a report of classification in terms of the decree of February 5, 1959.
The C.S.T.B. can carry out, on elements of small dimension, tests according to the official method, but it can not deliver a report of classification.

The structure of elements and products and their method of fabrication can be described only very briefly, and the table does not guarantee a classification, which can be obtained only by tests carried out in an official laboratory.[9] This information, nevertheless, will be useful to builders to conceive or improve the elements which they propose to subject to test.

(a) Doors

	Duration of resistance (minutes)	Classification by category (hours)
Solid oak door, 35 millimeters	CF[10] 32	1/2
37-millimeter particle board door (density = 0.500)	CF 27	1/4
Flush door with 5-millimeter plywood faces fire-retardant treated with paint on 2 faces	CF 19	1/4
Millwork door with 18-millimeter panels	CF 15	1/4
Flush door with 5-millimeter hardboard faces, veneered with wood	8	not classifiable
Flush door with 5-millimeter plywood	CF 5	"
Millwork door with 5-millimeter panels	CF 2-1/2	"

(b) Walls and partitions

100-millimeter dense panel of wood	CF 152	2
50-millimeter cement-excelsior panel with 15-millimeter layer of plaster on each face	CF 105	1-1/2
50-millimeter panel of pressed straw (density = 360)	CF 43	1/2
25-millimeter oak boards	CF 22	1/4

[10] C.F. = Fire break.

Partition composed of 16-millimeter particle board on the two sides and a grid of 0.04 meters by 0.04 meter strips	CF 20	1/4
Partition of 18-millimeter oak boards	CF 20	1/4
Partition of 25-millimeter fir boards	CF 18	1/4
Partition of 18-millimeter fir boards	CF 15	1/4

If one excepts the agglomerates in cement, it is seen that the woody materials (boards, plywood, or agglomerates) in maximum thicknesses, where they can currently be used in construction, can confer on walls and partitions only a 1/4-hour fire resistance.

These results confirm the possibility of increasing the fire resistance of an item by increasing the thickness of the material. Frequently it is possible to provide the duration of fire resistance of a composite material by adding the respective durations of its components.[11]

One will note that all the materials entering into the construction of the partitions shown in the table have a reaction to fire of average flammability or higher. On the other hand, the tests carried out have proved that fire-retardant treatments throughout wood-base materials show little of interest for increasing their fire resistance.

Curtain Walls

Curtain walls are the exterior elements of the construction which are prefabricated and which "close" the faces in the interval between the elements of the supporting structure. They frequently involve a solid wood interior framework, and their interior or exterior covering is sometimes of wood or derived from wood: niangon, sipo or pine siding, exterior plywood on the outer face; and plywood, particle board, or fiberboard on the interior face.

---

[11] In the case of an assembly of two similar panels separated by an air space, test results effectively indicate a fire resistance essentially double that of a single panel. But it is vital that the air space be compartmented laterally and vertically, otherwise it would create a chimney action ideal for accelerating the fire by permitting the flames to attack the two faces of the partition simultaneously with increasing violence because of the draft.

They frequently contain a window or French window and exterior coverings as described above, below, and to the sides of the window.

The safety services are rightly concerned with the possibility of transmission of fire from one floor to another, considering the openings. As a measure of prudence, any combustible exterior covering is currently prohibited, in principle.[12] But it is necessary to verify if such transmission is possible and, possibly, what the arrangements of the construction can render it improbable.

(a) Some tests are now being carried out in an experimental construction named "Lepir Furnace la,"[13] erected with the cooperation of the Association for the Development of Wood Use at the Experimental Station of the C.S.T.B. at Champs-sur-Marne. This construction involves two superimposed rooms, a ground floor and a first floor, separated by a concrete floor, with the possibility of installing, on occasion, a balcony jutting out from the facade. The rooms have three masonry faces, and the front part can be closed by attaching a panel in the plane of the facade or recessed.

A wood fire is kindled on the ground floor against the interior face of the panel. The quantity of combustible used represents 50 kilograms of wood per square meter of surface which permits obtaining the typical curve of temperature variation (fig. 4). For the standard test, each of the two panels contains a 1.80- by 1.25-meter window.

The concise report of the first four tests carried out in 1961 and 1962 states precisely the observations which were made (see table p. 45).

From these first tests, one can already conclude that a judicious combination of solid wood and plywood and asbestos-cement coverings permits making light panels with wood framing whose resistance to the passage of flame reaches 1 hour (maximum temperature 1,040° C.).

On the other hand, the presence and the amount of a recess influences considerably the possibility of the transmission of fire over the exterior across the bays. With a recess of 0.60 meter the maximum temperature on the surface exterior covering above the window was 160° C. at the 37th minute (test no. 2) which excludes any risk of ignition of a wood or plywood exterior covering. When the recess is reduced to 0.10 meter or when the panel is placed flush with the facade, the temperature on the surface of the upper

---

[12] D.T.U. of the curtain walls made of wood.

[13] Experimental laboratory for full-scale fires.

panel can reach 200° or 300° C., which can evidently cause the ignition of a wood covering.[14] But this surface combustion is slow. The fire resistance of the upper panel exceeds the duration of the test since its interior covering undergoes no appreciable heating (test no. 4), which excludes any transmission of fire to the interior of the upper story (figs. 8 and 9).

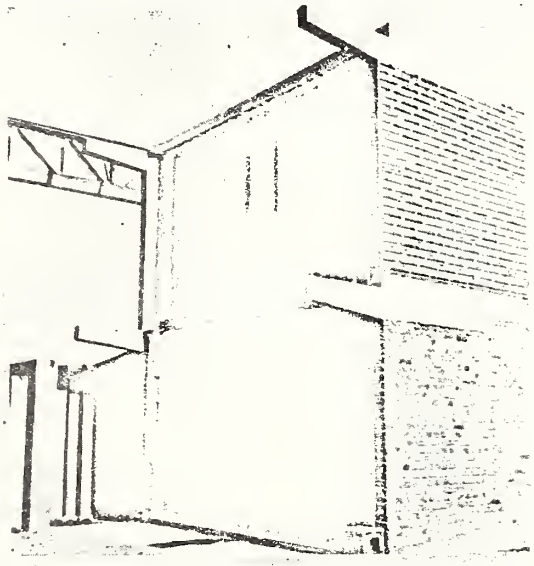


Figure 8.--Test No. 4. Curtain wall before test.

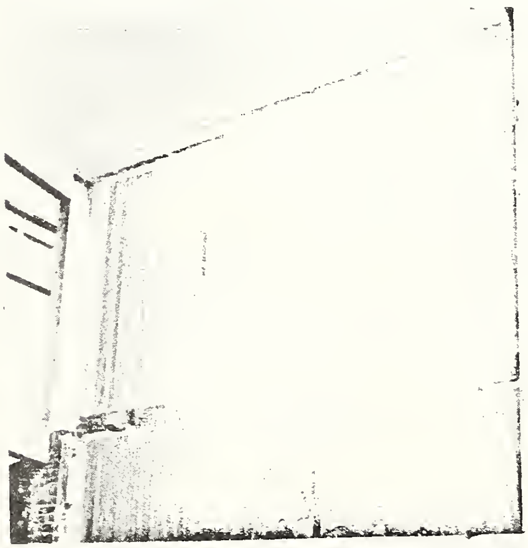


Figure 9.--Test No. 4. A localized ignition of the wood exterior covering of the upper panel has occurred. No notable heating of the internal face of this panel at the end of the test.

[14] In the case of ignition, the temperature of the burning part obviously exceeds 300° C.

(b) Tests carried out at the Centre Technique Du Bois on a reduced-scale assembly had for their objective an investigation of the influence of an incombustible break between two facing elements superimposed on a combustible exterior wall. At the same time it was proposed to check the minimum value of this break (0.80 to 1 meter for example) in order to prevent the transmission of fire, and the relative importance of the vertical and the horizontal parts of the break.

The photograph (fig. 10) taken during one of the tests shows the arrangement used (surface of the chamber, 7.5 dm^2).

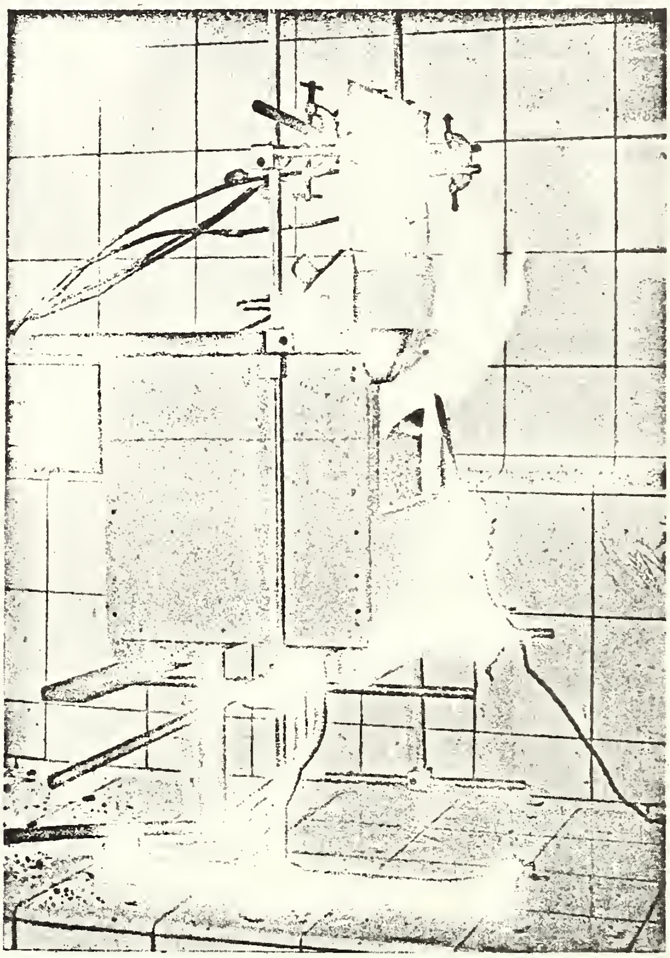


Figure 10.--Test carried out on model to determine the influence of the amount and orientation of the planes of the break between two facing elements (C.T.B.).

Test number and characteristics of the panels tested[1]	1		2		3		4	
	Temp.[3]	A.C.-R20	Temp.[3]	N.E.-R60	Temp.[3]	A.C.-R0 Gusty wind	Temp.[3]	N.E.-R10
Beginning of glass cracks, ground floor		3m 15s	500/5'50"	1m	500/6'20"	1m 15s		0m 40s
Beginning of glass failures, ground floor	500/3'35"	3m 17s	600/7'10"	6m 35s		6m 4s	500/2'40"	1m 42s
End of glass failures, ground floor		4m		7m 50s		8m 30s	600/3'40"	3m 15s
Appearance of flames on exterior	600/4'30"	4m 20s	700/10' 800/22'	6m	600/9'30"	8m (high)	700/5'40"	5m (very high)
Beginning of glass cracks, first floor	700/6'20"	5m 25s	900/28'	27m 30s	700/23'	10m 45s		8m
Beginning of glass failures, first floor	800/11'	7m 30s		44m		27m	800/9'30"	9m
End of glass failures, first floor	900/20' 800/31'30" 700/37'	(2)	800/47'	(2)	700/48'	(2)	800/28' 700/38'30" 600/45'30"	52m
End of test	600/41'30" 500°	45m	700°	48m	500/59' 480°	60m	500/51' 350°	60m

[1] 1st test A.C.-R20: Asbestos-cement exterior, insulation, plywood interior; recess 20 centimeters; ambient temperature 13°.
2nd test N.E.-R60: Niangon siding exterior, insulation, plywood interior; recess 60 centimeters; ambient temperature 10°.
3rd test A.C.-R0: Same panel as test No. 1, but interior covering fiber-cement mounted without recess; ambient temperature 8°; wind gusts 18-50 km/h.
4th test N.E.-R10: Same panel as test No. 2; recess 10 centimeters; ambient temperature 14°.

[2] Partial failures.

[3] Average of temperatures recorded at the ceiling of the ground floor. Example: 600/4'30" = 600° reached at 4 min. 30 sec.

All possible combinations between the vertical and horizontal parts were tested within limits varying between 0.30 and 1.60 meters (6 to 32 centimeters to scale).

It appeared that the horizontal portion in the form of a recess or a projection had the preponderant influence and that the accepted addition rule[15] must be modified.

This group of studies has brought out the possibility of fully accepting wood and wood-based materials in this type of element. But they show the importance of particular features seeming to be secondary: strength of systems for assembling and erecting the panels, makeup of the lintel, presence or absence of an air space in the panel, and, of course, the conditions of placement, particularly the recess with respect to the surface of the facade.

The tests have also revealed the imperfection of current experimental methods and the difficulty of reproducing comparable conditions for successive tests. It is especially difficult to follow exactly the typical temperature curve in each of the experiments.

Wall Coverings

It has been seen earlier that when the energy radiated by the initial source was intense, there occurred a generalized and sudden ignition of all the combustible material in the enclosure where the fire has taken hold ("flash over"). It has been noted that the delay before this phenomenon occurs depends among other things on the nature of the walls, floors, and ceilings or of that of their coverings (figs. 11 and 12).

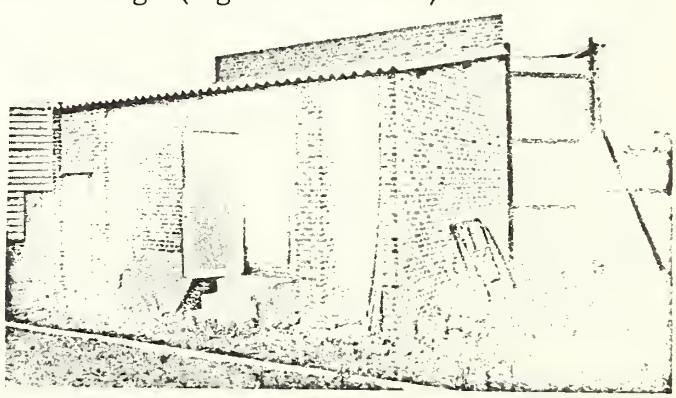


Figure 11.--LEPIR furnace constructed at the Experiment Station of the C.S.T.B. at Champs-sur-Marne.

[15] Total included between 0.80 and 1 meter.

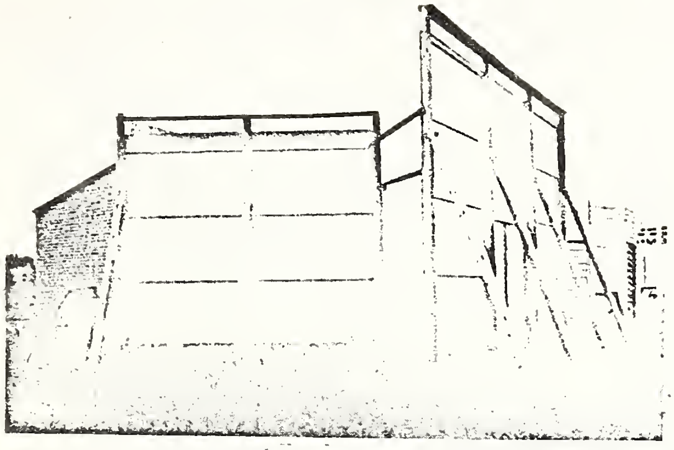


Figure 12.--Wind shields sheltering the LEPIR furnace at Champs-sur-Marne.

In order to study the behavior of various partition or wall covering materials or floor and ceiling coverings, the C.T.B. in cooperation with the C.S.T.B., has had built a special furnace at the Center in Champs-sur-Marne (Lepir 1c) (figs. 13 and 14).

On the other hand, it has studied and experimented with a reduced-scale model of this furnace (Lepir 1/3). Later photographs show various phases of the standardization of this apparatus.

The state of advancement of investigations of "flash over" still do not permit, currently, to state precisely in what measure the wood and wood-based materials used in interior coverings increase the risks of accelerating the propagation of fire and of spreading it to all combustible surfaces. It will be reported in systematic fashion and detailed when usable results have been furnished.

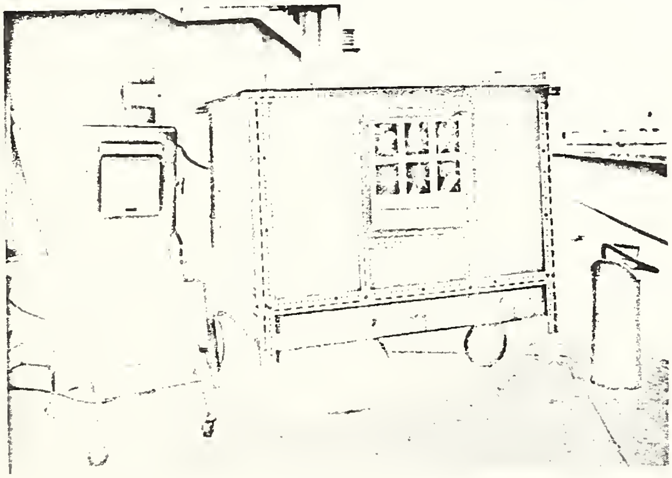


Figure 13.--Reduced-scale (1/3) furnace used at the Centre Technique du Bois.

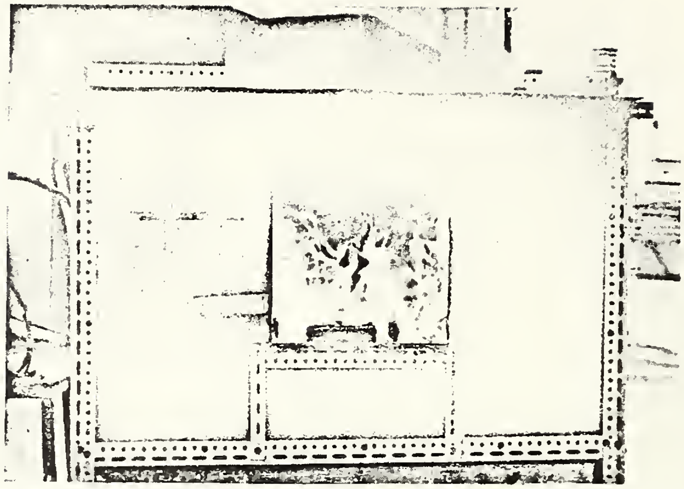


Figure 14.--Test in the reduced-scale furnace.

CHAPTER V

REGULATIONS FOR THE USE OF MATERIALS OF CONSTRUCTION IN FRANCE AND IN VARIOUS COUNTRIES FROM THE POINT OF VIEW OF FIRE RISK

1. French Regulations

Regulations established in France to prevent risks of fire in buildings involve both provisions relating to materials of construction and elements and prescriptions concerning the location and the arrangements of the exits.

The first type rests on the qualification of materials or elements of construction from the point of view of reaction to fire (ignition and speed of combustion) and of resistance to fire.[1]

The latter tend to assure means of evacuation and of rescue.

---

[1] Decree No. 57-1161 of October 17, 1957 (Official Journal of October 20, 1957) and Ministerial decree of December 9, 1957) (Official Journal of January 16, 1958) (reaction to fire).
Ministerial Decree of January 5, 1959--resistance to fire--commentary on the annex to the circular No. 162 AG (Official Journal of March 2, 1951 (classification of materials of construction).

From the point of view of its application, this regulation is divided into several groups of subjects. Some concern constructions receiving the public: hospitals, churches, theaters, schools, etc. Others concern habitations. Finally, exhibitions, fairs, and expositions are the object of separate regulations the same as buildings classed as dangerous.

(a) Establishments receiving the public.--In these constructions, public authorities are primarily preoccupied with the simultaneous evacuation of many people. The elimination of materials favoring, in themselves or by their method of placement, rapid and generalized spread of fire is, with the fire resistance of the basic structure, the essential condition. With a view to establishing these prescriptions, the establishments have been classified according to the number of people which they can shelter, in four categories numbered 1 to 4 in decreasing order of number of occupants.

Some common provisions, whatever the activities of these establishments, are decreed for each category.[2]

Particular provisions concern, besides, a certain number of establishments according to their nature (Title IV).

Here, very briefly summarized, are those of the common provisions which touch on the nature and the method of use of materials of construction. Construction proper (Section III of Chapter II):

The basic structure must have a fire resistance of 4 hours for establishments of the first 3 categories and of 2 hours for those of the fourth category.

Only paneling, trim, and flooring of hardwood bonded on the whole lower face to fully incombustible walls or masonry are accepted.

Stairways and steps must have the same resistance to fire as the basic structure. Hardwood is tolerated provided it is protected on the under face by masonry of 1-hour resistance. Interior arrangement: (section IV of the same chapter).

--Interior partitions separating rooms must have 1-hour resistance.

Covering materials must be nonflammable or, at least, difficult to ignite by their nature or their method of application. In the last case, their

---

[2] Title II of the safety regulation published in the Official Journal of September 3, 4, and 5, 1954. Sections III and IV of Title II concern construction and interior arrangement (choice of materials and their application, construction of elements).

thickness except, in the case of the paneling mentioned above, will not have to exceed 5 millimeters.

If the coverings are attached to laths or furring, their distance from the wall must not exceed 5 centimeters, and the free space must be partitioned horizontally and vertically. Furring strips of hardwood are accepted if their thickness does not exceed 35 millimeters (width 5 centimeters) and if they are protected laterally by masonry filling for the full thickness.

--No gas pipe or electrical conduit can be placed between the wall and the covering.

These very precise provisions have, practically speaking, repercussions on wood use in this type of construction only for panels placed on cellular cores or laths. They impose gluing or continuous attachment on incombustible supports except if the wood-based panels are fire-retardant treated. These restrictions affect partitions, interior arrangement, and decoration. The basic structure is not generally of wood, and hardwood floor coverings, which are nearly always placed on a slab of concrete or masonry, are for this reason, authorized.

(b) Safety measures concerning habitations.--In habitations where people are found asleep, ill, or infirm, it is important to conserve, as long as possible, the possibility of evacuation and of intervention. It is necessary also to delay the noxious or explosive action of the combustion gases. One is thus concerned not only with the speed of propagation of fire but also particularly with the resistance of the partitions to prevent as much as possible the passage of smoke, gas, and flames to the corridors, landings, and stairways.

In multifamily buildings, there is less fear of transmission from one area to another by combustible materials (there are usually breaks), as by elevator shafts, or heating and ventilation ducts. This explains why, contrary to the preceding case, the prescriptions look less to the nature of the materials than to the arrangement and the fire resistance.

Moreover, it is not possible, for reasons of construction cost, to prohibit entire classes of material whose reaction to fire by the epiradiator is judged insufficient. It is necessary to establish distinctions based on real risks, distinctions which this method of test do not permit. One finds, for example, in the "easily ignitible" category, a 12-millimeter oak board or about the same as manifestly very dangerous materials. Perhaps the perfection of a different method of test for the reaction to fire (speed of combustion) analogous to English or American methods would permit separating eminently dangerous substances.

Circular No. 5871 of November 14, 1958 and the technical notice of the C.S.T.B.[3] state precisely the conditions which have to be fulfilled, from the point of view of fire safety, by the buildings for habitation contemplated by article 92 of the Code of Town Planning and of Habitation.

In its Title III, devoted to fire resistance and to protection in case of fire, the technical notice establishes four categories of buildings according to height:

1--Individual or double habitations

2--Individual habitations in rows or of two stories maximum.

3--Buildings of more than two stories and whose last inhabited floor is not more than 28 meters above ground level.

4--Buildings of greater height than those of the preceeding category.

These prescriptions are much more flexible, as concerns the use of materials, than the provisions adopted for establishments receiving the public. Few of them are such as to prohibit the adoption of woody materials or to limit their placement except in certain access ways (corridors, stairways, elevator shafts), in ventilation or heating ducts, in utility shafts, etc.

Fire resistance requirements for the basic structure affect wood very little. For individual homes, 1/4-hour resistance (1st category) is easily attained. In larger buildings, where the degree of resistance required is higher (1/2 hour to 1 hour depending on the elements[4] for the second and third categories and 1-1/2 hour for the fourth category), wood or wood-based materials are used only very occasionally as structural elements.

Besides, it has been seen that it is easy to make solid or glued-laminated framing or posts whose fire resistance exceeds 1/2 hour.

To the contrary, except for habitations of the first category, the exterior coverings have to be incombustible.

---

[3] C.S.T.B. Report No. 283, December 1958, in application of the decree of October 22, 1955 (Art. 2) and the decrees and published instructions of the Official Journal of November 17 and 18, 1958.

[4] One hour for vertical elements in the second and third categories and the floors of the third category, 1/2 hour for floors in the second category.

One should be careful to prohibit large, continuous combustible surfaces involving, without breaks, several apartments on the same floor or several floors, on several tens of meters of height and width.

It is regrettable that a distinction has not been made between this eminently dangerous concept and the placement of isolated facing elements with not easily ignitible coverings, separated from one another by breaks. It is evident that it is at least necessary to carry out some tests in order to try to define the risks in the second case.

This is why the Centre Technique du Bois has undertaken, in cooperation with the C.S.T.B., to carry out a program of tests; the provisional results were given in the preceding chapter.[5]

Current French regulations, which we have summarized briefly, appear to be a logical but arbitrary assembly insofar as they concern the use of wood and wood-based materials. If experience has shown their real effectiveness, they will, however, have to be perfected, and their improvement will consist above all of removing with discernment certain prohibitions which, perhaps, are measures of prudence but which will not have to be maintained if experience demonstrates their lack of utility.

However, any regulation in itself involves disadvantages. Its very existence incites architects and entrepreneurs less to instruct themselves on real conditions of safety than to avoid any infraction of the regulations, the more so as they are more complex. Safety Commissions, on their side, with concern for effectiveness, frequently exceed the prescriptions in their severity; also the constructors, afraid to find themselves through lack of knowledge in contravention of more and more complex regulations, prefer to abstain from using combustible materials; and we have seen that this is not always an efficient way to reduce risk.

Everyone, thinking thus to cover their responsibility, abdicates all initiative, which is serious, because the application of regulations which are not able to foresee everything always leaves gaps, which a clear notion of objectives to be attained and simple good sense would avoid.

2. Foreign Regulations

It is difficult to give an exact idea of the conditions really imposed on construction in foreign countries. The information collected, sometimes

---

[5] See Chapter IV.

rather complete, does not indicate the practical application of the regulations. On the other hand, many of the regulations are purely local, and it is impossible to give any more than the tendencies which prevail in their establishment. Others are complex, because although established on a national plane, they are set up on a territorial basis. Others, more simple, consider only the nature and size of the buildings whatever their site; it is the latter type to which the French regulations belong.

--As concerns the establishment and control of the application of these regulations, there are three tendencies:

1.--Drawing up, application, and control by local authorities. Alone, these directives suggest a common orientation on a national plane (Ex., USA, England, Holland).

2.--Regulations established by national bodies (ministries in charge of construction) and powers of application and control delegated to regional services (Japan, France).

3.--Total centralization on a national scale of the functions of regulations, application, and control (USSR and Sweden).

The qualification of materials is based on prescriptions related to the construction in every country, but the criteria differ.

A distinction is always made between flammability and speed of combustion (reaction to fire) on the one hand and fire resistance on the other. Fire resistance tests differ but little from one country to the other, the exposure temperatures following essentially the curve adopted for the French tests.[6] The results are comparable.

The methods of determination of flammability and of fire spread are, on the contrary, very different. The idea of flammability (temperature and time to appearance of flames) has been abandoned in Great Britain, in the United States, and in Holland as being too variable to give a valid indication of the behavior of materials in service. It is preferable to make a separate determination of combustibility (furnace at 750° of the B.S.I.) and of speed of spread of the fire (English radiant panel or the tunnel test in the USA).

France, on the contrary, has retained a mixed test (flammability, spread, combustibility, involved simultaneously for classification from the point of view of reaction to fire). We have brought out earlier the disadvantages of

---

[6] See page 23 and ASTM E119 (USA), BSI 476 (Great Britain).

this test if one wants to deduce from it the true behavior of materials.[7] It presents disadvantages also for the relative classification of materials inasmuch as we have seen that it does not permit separation, in the range of easily ignitable materials, products whose risks in use are very different. The practice of different tests is more selective, although it furnishes, on the contrary, less precise indications toward the higher range (average and especially difficult ignitability).

In every way, the divergence between methods shows their imperfection.

Prescriptions relative to use of materials and to conditions of use differ considerably from one country to another, but it is difficult to establish a comparison, even roughly, because the rigor with which they are effectively applied is variable, and because certain of them have the character of a simple recommendation, the conditions of local application being unknown. For example, in England, ministerial recommendations require incombustibility for construction materials, and wood is theoretically excluded from exterior walls of multi-family dwellings having several floors. Practically, solid wood and plywood are utilized as exterior coverings of facing panels with large breaks (alternate floors).

It will be remembered, however, that, for certain categories of current construction defined by their nature, ground area, number of floors or geographic location, the restrictions imposed on the use of wood are much less severe in the countries which have a long experience in its utilization in buildings (Japan, Sweden). It seems that a good knowledge of the problems of the all-wood house, for which precautions are absolutely necessary and observed by some sort of instinct by the constructors, preserves these countries from a systematic distrust.

Despite these differences, it is necessary to note that, in all these countries, the principal prescriptions bear on the fire resistance of the basic structure (which does not necessarily exclude the use of wood), low flammability of coverings (interior and exterior), and safety of evacuation.

The prescriptions are more severe for constructions having a ground area exceeding 200 meter^2 and for those with more than three stories. They are also, naturally, more rigorous for buildings receiving the public.

---

[7] See page 12.

CHAPTER VI

CONCLUSIONS

Regulations of the use of materials in construction is a necessity as a consequence of the evolution of city planning toward large collection of buildings of increasing size. The use of new materials or the appearance of nontraditional forms of utilization also necessitates examination and control.

But it is not by tightening this regulation and by supressing the use of any combustible material that total safety is assured, dispensing with all other precautions. It is necessary for architects, entrepreneurs, and the public to be on guard against this dangerous simplification of the problem. Experience demonstrates that, in order to avoid fire, it is necessary first to reduce the risk of initial ignition and to remember that materials other than structural stored in the area, most frequently constitute the first and necessary fuel for the fire and are the principal cause of its development.

It is necessary for the public to be on guard against the false assurance of buildings called "fireproof" or "noncombustible"; fireproof construction does not exist. From the point of view of the builder, it is only necessary that the building elements do not constitute a considerable fuel source for a fire and are not susceptible to increasing the violence and development of the fire or of jeopardizing the evacuation of the occupants or the intervention of the fire fighters. This point of view has to be envisaged with all materials of construction even if they do not burn, because their behavior affects the development of the fire and its consequences. One will read with interest on this subject the opinion of Commandant Etienne, Technical Adviser to the Ministry of the Interior, on the behavior of different systems of framing.

Qualification tests, despite their evident interest, should not be the essential criteria of a regulation. It is useless to eliminate wood when its presence creates no predominant risk, while certain materials that could be substituted for it can, to the contrary, be dangerous. What must be furnished is an equal resistance to fire for the whole structure.

If the two criteria of reaction to fire and fire-resistance pose problems for the use of wood, it must not be forgotten that the tests carried out, like experience, confirm the position of the defenders of wood. If the latter suffers from fire, as do all materials of construction, it does not behave worse than most of them. It is known that, used in large thicknesses, it has good resistance to fire, compared with steel, as has been shown by simultaneous

tests of wood and metal posts. It cannot be ignored that a solid-wood door or partition is a good fire barrier, more effective than a metal door, or that a solid wood framework is destroyed only slowly, continuing to assume its supporting role during the most violent fire without risk of subsidence or sudden collapse.

Certain precautions, most of which are based on common sense, permit avoiding serious risks. In certain cases when it is a question of nontraditional elements, experimentation is required in order to determine their structure and their conditions of use in order to mitigate the risks.

Under these conditions, why would architects, builders, and users, and even certain authorities charged with applying safety regulations oppose in a systematic fashion the use of wood in construction? This ostracism does not fulfill their responsibility and can only serve the skillful propaganda of competing materials. It is not based on an assembly of precise, observed facts but only on preconceived ideas. Can one conceive that a public building or an apartment building, with its fittings, its furniture, its curtains, hangings, rugs, the paper, the linen, the books which it must contain, is totally protected from fire because one has eliminated some floor surfaces, some cabinets, or some doors?

It is necessary, certainly, to take all useful precautions in order that fire does not start nor develop rapidly because of wood elements, but these measures, which affect thin elements especially, have to be taken knowingly during examination of the whole design, plan and specification and not with the over-simplified idea that when one has eliminated wood he will have made decisive progress toward safety.

Rather than eliminate some materials without appeal on the basis of the test for reaction to fire, whose interpretation is so difficult, it is essential to state precisely the objectives to be attained in order to assure the safety of persons.

It is thus very desirable that a regulation concerning the use of materials in construction be quite flexible and adaptable to all innovations of progress. If some measures of prudence are imposed initially, counter to flammable materials or to new construction procedures, it is not necessary that they be final and considered as panaceas covering all inconsistencies. In the matter of safety, no one can evade his moral responsibility, which is the best guarantee of study and of conscientious effect at all levels.

APPENDIX

THE BEHAVIOR OF WOOD FRAMING AND OF STEEL FRAMING

At the end of the 19th century and the beginning of the 20th, the Americans experienced serious mistakes with their constructions called "fireproof," under the test of fire.

The conflagrations, spectacular as well as catastrophic, of Chicago, 1871, Baltimore, 1904, and some others[1] which were prolonged--in time as well as space--led to a commendable reaction, certainly, but somewhat superficial and which led to the mistakes mentioned earlier.

This reaction, which consisted of eliminating any combustible material from construction, introduced a risk for want of sufficient reflection; one had not thought of the poor behavior of metal--steel principally--in the face of fire.

This risk is too well known for us to lay stress on this bad behavior; the literature relative to fire is sufficiently large on the question and we will content ourselves here in suggesting to the reader that it would be of interest.

If, however, steel does not burn (except under certain special conditions), it should be noted that its principal disadvantage in construction is its expansion, as well as the loss of mechanical strength which always accompanies it.

As an aggravating circumstance, the effects of this almost total loss of mechanical strength manifests itself not only at the initial source of the conflagration but, frequently, at a great distance from it.

On this subject, among the numerous fires at which we have given assistance, we will cite that which occurred in February 1940 in the Pathe film studios at Joinville-le-Pont (Seine) where, despite its size and its violence, the source proper involved only a small fraction of the area destroyed--about 1/4. Thus the greatest part of the damage--collapse of the roof and the walls--was caused by the nature of the framing and the metallic skelton of the construction.

---

[1] Boston, 1872, Toronto, 1904, San Francisco, 1906, etc.

What would have occurred if this framing and skeleton had been of wood?

The fire would certainly have been as violent, perhaps even more so, but its effects would have remained localized, and the control actions would have been limited essentially to its proportions at the beginning.

In our opinion, it is time to stop this erroneous legend of the fire danger presented by wood. Certainly, wood is combustible; it is not a question of denying that here, but it is especially combustible when it is divided; when it is a question of beams or of planks of large section, its combustion is infinitely less rapid and its loss of mechanical strength from heat is much less than that of steel. In addition, as has been seen earlier, the effects of this combustion are strictly localized.

Under these conditions, it is difficult to understand the legislators, technicians, and preventionists who impose or recommend--in the case of buildings having to shelter materials dangerous from the point of view of fire--a steel frame. A practice, alas, already long, of combatting fire authorizes us to prefer wood to metal in all constructions menaced by the risk of fire. We hope that this conviction is shared by all those, near and far, who are involved, in any way whatsoever, with the fighting of fire in buildings and in construction.

Commandant Etienne

Technical Adviser to the

Ministry of the Interior